ENGINEERING FOR ALL

Vertical Farming: Fresh Food for Cities

Korbin Shoemaker's Class, Walkserville Middle School

TEACHER GUIDE

Vertical Farming is a unit of the Engineering for All project, developed by Hofstra University in collaboration with the International Technology and Engineering Education Association (ITEEA).

This unit, and others in the Engineering for All project are made available to the public through the Engineering by Design curriculum from the ITEEA.

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Current Units in the Engineering for All (EfA) Series

Engineering for All (EfA) is a series of curriculum units for technology students and teachers. At present there are two units in the EfA series:

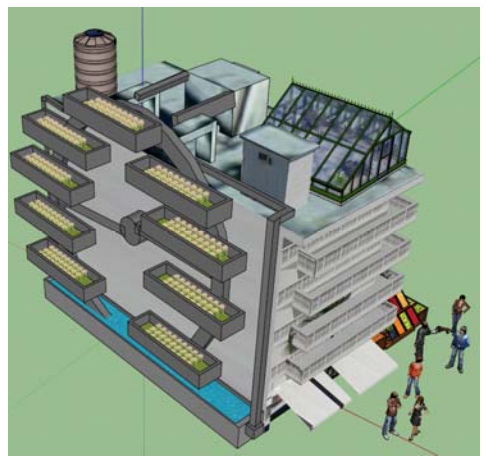
Water: The World in Crisis

To address the grand challenge of improving water availability and safety, students will explore issues of water scarcity, including the effects of unsafe water, water contaminants, and water filtration methods. The unit begins as students are told they have been accepted to be part of a team of engineering students that will be working with the local chapter of Engineers across Borders. Students learn about the world water crisis and water scarcity and become "experts" in "traditional" design and construction of contaminate removal/filtration systems.

Upon the completion of their water exploration tasks, students are presented with the Grand Challenge; student groups will design and construct a water filtration system for a single family in a specific developing country, using only locally available materials. Groups work to design the best possible system. Students then present their system to the staff of Engineers across Borders (Principal and others) and to classmates. Classmates critique each system and select the best features of each, then redesign into one optimum filtering system. The overarching goal of this unit is for students to develop engineering design and systems analysis skills while coming to understand that engineering has great potential to be a social good.

Vertical Farming: Fresh Food for Cities

In order to address the grand challenge of producing food for a growing world population, students become "experts" in designing and constructing hydroponic systems. Once their hydroponic systems are up and running and plants are growing, the students receive a message that their firm has been asked to design a hydroponic system for the wall of an existing apartment building.



Middle School Student Project, Salem, Oregon

Small teams compete to design the best possible system. Their work culminates in design drawing and a presentation to their classmates, who will consider each design on its merits, and then work together to plan the best possible design for their client. The overarching goal of this unit is for students to develop engineering design and systems analysis skills while coming to understand that engineering has great potential to be a social good by solving such critical problems as providing food and water for people around the world.

UNIT OVERVIEW

According to the United Nations, the world population of more than 7 billion is expected to increase by nearly a billion people within the next twelve years, reaching 8 billion in 2025 and more than 9 billion in 2050.[1] As the world population increases, so will the demand for food. Producing enough food for growing populations will be an immense challenge.

An idea that has been suggested to solve the problem of insufficient food is for city dwellers to grow some of their own food in tall buildings. Although websites display a number of exciting buildings designed to be vertical farms, the cost of land and construction in large cities make new building impractical at present. However, hydroponics and vertical farming do not necessarily require new construction. The challenge for the unit is to design a vertical farm that will grow vegetables hydroponically on one or two sides of a large apartment building.

The unit begins as students are invited to join a small engineering company that designs hydroponic vertical farms. The students are told that in order to design a vertical farm themselves they first need to learn two skills: hydroponics and computer aided design (CAD).

The students learn these skills in a series of five Knowledge and Skill Builders (KSBs).

KSB1 explains the nature of the problem, the idea of vertical farming, and provides an introduction to hydroponics.

KSB2 challenges the students to design and construct a platform to hold their hydroponic systems. The students learn to follow the Informed Design Process and to use a decision matrix to choose the best design.

KSB3 involves designing and building hydroponic systems. Teams of students are assigned to construct one of two different systems. The focus of this KSB is on the nature of systems.

KSB4 involves planting, monitoring, and harvesting plants. The focus of this lesson is that feedback is essential for maintaining systems.

KSB5 presents a series of lessons in computer aided design. Students learn to use SketchUp, a free CAD software package, guided by a series of tutorials constructed by a middle school teacher.

In the Grand Challenge students receive a letter from their first client, asking them to design a vertical farm. The students apply what they learned in the previous KSBs to meet the challenge and present their ideas to the client.

The overarching goal of this unit is for students to develop engineering design skills while coming to understand that engineering has great potential to be a social good by solving such critical problems as providing food and water for people around the world.

[1] *UN, 2012. World Population Prospects: The 2012 Revision.* New York: The United Nations. Retrieved from: http://esa.un.org/wpp/

Engineering for All

The primary target group for the EfA units is middle school engineering and technology education (ETE) students and teachers, since the shift to STEM education substantiates the need for the nation's 30,000 TE teachers to play an expanded role in advancing the *T* and *E* in STEM for *all students*. The purpose of these units is to enable students to develop predispositions to forge a sustainable future and learn that engineering is a route to engage in socially significant work. When completed, the EfA modules will become part of the International Technology and Engineering Educators Association's flagship *Engineering by Design* (EbD) program.

Vertical Farming is part of the *Engineering for All* (EfA) project, which has been funded by the National Science Foundation (Grant # DRL 1316601) to create, test, and revise two-six week modules for middle school technology education classes on the important social contexts of *food* and *water*. The units are built on three "drivers" that underpin the Engineering for All approach. These are discussed below and include:

- Promoting engineering as a social good
- Applying themes in authentic social contexts
- Using *informed design* as the core pedagogy

Promoting engineering as a social good

Due to the essential roles engineering and technology play in addressing global and environmental challenges, support for ETE programs has rapidly increased. In addition to the workforce and economic imperatives, engineering can and should be appreciated as a contributor to sustainable development and transformative improvement in quality of life. The UN *Millennium Development Goals* and the NAE *Grand Challenges for Engineering* inspire development of curricula that prompt learners to seek solutions to human needs: potable water, sanitation and waste disposal, energy, sustainable transport, and production of sufficient food to meet the needs of a growing world population.

School-based engineering meets the needs of millennial students who are civic-minded, team-oriented, and want to make a difference. There is growing recognition that ETE experiences can be pedagogically valuable for all students—not only in providing an effective way to contextualize and reinforce STEM skills, but also in mobilizing engineering thinking as a way for young people to approach problems of all kinds.

Applying themes in authentic contexts

EfA has adopted the following **five unifying themes** (design, modeling, systems, resources, and human values) that align well with both the Standards for Technological Literacy (ITEEA, 2007) and the Next Generation Science Standards (NGSS Lead States, 2013).

> **Design** relates to the process engineers (and others) use to develop solutions to problems. The Accreditation Board for Engineering and Technology (ABET) defines design as "the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a

stated objective" (ABET, 2000). Multiple solutions can be suggested with different benefits and burdens. The search is for an *optimal* solution that meets design criteria; and tradeoffs between what is desired and what is feasible within real-world constraints of time, money, availability of resources, laws of nature, politics, etc.

Modeling involves developing representations of a solution (representational modeling) that help engineers test the effects on product performance of changing variables on a design or to depict how a design actually works. Models can be drawings; functional physical models (either made to scale or full-size); simulations (virtual models); or mathematical models. They can be used to describe a design (CAD is a form of descriptive modeling) or to predict how it might work (Simulations are a form of predictive modeling). The use of modeling, with its inherent predictive analysis, is a central theme in engineering. Modeling (and analysis) in the design process is important because design ideas cannot always be evaluated by the build-and-test approach since it is often too costly and time-consuming to do so.

Systems Thinking relates to conceptualizing an engineered system, product, or process in terms of it being comprised of a set of interrelated components or subsystems that act together to produce a desired result. All systems include inputs, controllers, processes, and outputs. System inputs are of two types: the *command input* (which specifies the desired result); and *resource inputs* such as energy, information, and materials that are combined by the system process to produce outputs. A system is designed to turn desired results into actual results. Often, actual results include both intended and unintended outputs. Systems can be open-loop systems (where the system does not alter its output based on changing conditions), or closed-loop systems that operate using feedback to respond to changing conditions.

Resources are broadly classified into several categories: people, capital, energy, information, materials, tools/equipment, and time. All technological systems use some or all these resources. Engineers select and use the most appropriate resources based on their availability, cost, and how appropriate they are for the setting in which they will be used. When engineers choose resources, tradeoffs are often made (plastic may be substituted for metal; human labor can be substituted for capital intensive machinery). Resources are chosen to accomplish desired results safely, economically, and efficiently.

Human Values must be taken into consideration when proposing solutions to design problems. When doing so, engineers try to take cultural mores and preferences into account. Tradeoffs that might be made between profitability and a design's impact on the environment (e.g., sustainability and disposability) and on people's health and safety must be carefully considered.

Donovan & Bransford (2005) suggest that concepts must be placed in a conceptual framework to be well understood and "take on meaning in the knowledge-rich contexts in which they are applied; " and, to deepen conceptual understanding and facilitate learning transfer, students should encounter the same idea in a variety of contexts (de Vries, 2010; Bransford & Brown, 2005).

EfA themes will be revisited in **two social contexts** (food and water) that are relevant to students and relate to improving quality of life. Revisiting the themes in different contexts will facilitate learning transfer and provide a more holistic understanding of engineering.

Informed design as the core pedagogy

Informed design enables students to enhance their own related knowledge and skill base before attempting to suggest design solutions. In this way, students reach design solutions informed by prior knowledge and research, as opposed to trial-and-error problem solving where conceptual closure is often not attained. Informed design emphasizes design challenges that rely on math and science knowledge to improve design performance. The approach prompts research, inquiry, and analysis; fosters student and teacher discourse; and cultivates language proficiency.

Implementing the informed design process involves engaging students in a series of Knowledge and Skill Builders (KSBs) that they will need to solve a Grand Challenge. Solving the challenge involves eight stages: clarify problem criteria and constraints, research and investigate, generate alternative designs, choose and justify the optimal solution, develop a prototype, test and evaluate, redesign the solution, and communicate your achievements.

Teaching the Vertical Farming Unit

Planning

Plan this unit at least a month in advance so you'll have time to order all the supplies and materials. We recommend that you start with just one class, since there is a learning curve with hydroponics. Also each system has about a 2' x 3' footprint, and requires several electrical outlets. The supplies, which cost about $950 can be reused by other classes at a later time, with the additional cost for consumable materials of about $150 per class. We recommend that you:

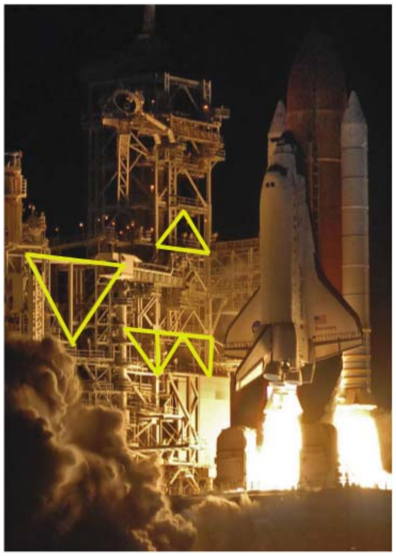
1) Read the following one-page summaries of each of the lessons. These are provided to help you plan the overall course, and also to use as a refresher before beginning each new lesson. More extensive descriptions start on page XX.

2) Read the subsequent section, "Hydroponic Tips from Korbin Shomaker." Korbin is a middle school teacher with considerable experience in hydroponics. Reviewing his suggestions will provide a very good grounding in how to teach the practical skill of hydroponics to middle school students.

3) Test the water source closest to your classroom, following Korbin's suggestions, to find out if you will need to obtain a water filter or if tap water will do.

4) Check out the electrical outlets in your classroom to decide where the students will set up their hydroponic systems, and how many power strips you'll need.

First Four Days (Introduction to Engineering for All)



NASA, Public Domain

Overview (Days 1-4)

Like all projects in the Engineering by Design series, the unit is launched by an introductory lesson called The First Four Days. The students first do a short activity to "Build The Tallest Tower," without instruction. They then learn how to design stable structures, guided by the eight steps of the Informed Design Process. They then apply the Informed Design Process to the subsequent unit, Vertical Farms: Fresh Food for Cities.

Lesson Duration: Four 45-minute periods

Big Idea: Engineering aims to benefit society and the environment and is accomplished through collaboration and problem solving.

Learning Activities

Engage: Students are given a bag of supplies and told to "build the tallest free-standing tower that you can that will support the weight of golf ball for at least two minutes." Teams are allowed 20 minutes to plan and build. They are not given any instruction about the Informed Design Process at this point.

Explore: Students explore the materials, then build their towers. Towers that hold the weight of a golf ball for at least two minutes are measured and a "winning team" is declared.

Explain: The teacher presents the Informed Design Process, commenting on the difference between the trial-and-error approach the students just completed and engineering guided by the Informed Design Process. Student teams then undertake a series of short activities in which they construct and test squares, diamonds, and triangles made from paperclips and straws. The activity concludes as students explain what they learned about the stability of various shapes.

Engineer: Students are asked to "Think Like an Engineer" and redesign their towers using the same materials; but this time applying the knowledge they caned from the activities with shapes and the Informed Design Process.

Enrich*:* Students view images of bridges, towers and other full scale structures, so they can see the connection between their activity and how professional engineers build structures that help society.

Evaluate: Students reflect on the Big Idea, and how it relates to the activities that they completed. The lesson concludes with a few broad questions about the value of the Informed Design Process in daily life, and the skills that the students will need to become better at solving problems.

KSB1. Welcome to Fresh Food Engineers

Courtesy of Cary Sneider

Overview (Days 5, 6)

Students are informed that they have been hired to work in a small engineering company that specializes in hydroponic systems design. One day they will be asked to design a large vertical farm, but first they need to learn about hydroponics and CAD. The KSB then introduces students to the need to feed a rapidly growing population, the pros and cons of hydroponics for solving the food problem, and describes four different hydroponic systems.

Lesson Duration: Two 45-minute periods

Big Idea: Sustaining the supply of food is a great engineering challenge, especially as the world's population grows.

Learning Activities

Engage: Hand out KSB 1 (or open on computer or tablet). Discuss the idea of *food deserts*, pointing out that difficulty in obtaining affordable fresh fruits and vegetables leads to poor health.

Explore: Have students access the U.S. Department of Agriculture's Food Access Research Atlas on the Internet. The assignment is for students to zoom in on the area where they live, or other areas they know personally, and use the key to see if it is a food desert. Then have students read about the global problem of feeding a growing world population with dwindling land and water supplies suitable for farming.

Explain: Introduce the idea of vertical farming. Buildings constructed for vertical farming have been designed, but it is expensive to construct new buildings in cities. However, growing food on the surface of existing buildings is a very promising idea. The students' grand challenge will be to design such a vertical farm. First, however, they will need to learn to grow foods hydroponically and learn to use Computer Aided Design.

Engineer: Use a video projector to show and discuss the diagrams of the four hydroponic systems on pages 6, 7, 8, and 9. Have students research these and other hydroponic systems using the Internet.

Enrich*:* Have students search for and view videos about agricultural engineering and vertical farming. Challenge them to find examples in which food is grown on the walls of buildings.

Evaluate: Have students complete Check Your Understanding and What's the Big Idea? to determine what they learned from the KSB.

Assessment: Examine students' responses to the questions at the end of the unit. Discuss these ideas with the students to reinforce the most important or misunderstood concepts.

KSB2. Design and Build a platform

Courtesy of Cary Sneider

Jake Cogger's Class, Salem, OR

Overview (Days 7, 8, 9, 10)

This is a key lesson in which students learn to engineer a product. Students are shown the materials that they will use (either wood or PVC tubes). They are given the challenge of designing a platform that will hold the growing chamber and reservoir, allow for tubes to pass between them, and hold lights that can be adjusted. The teacher guides the students in designing their platform, creating a bill of materials, making tradeoffs, and using a design matrix. Students build their platforms.

Lesson Duration: Four 45-minute periods

Big Idea: The Informed Design process uses knowledge and skills to solve problems rather than just trial-and-error.

Learning Activities

Engage: Organize the class into six teams. Tell the students that their task is to design a platform that will hold both parts of the system, and that will hold lights suspended above the plants. Explain why the platform is needed, and the criteria and constraints of the task. Introduce the Informed Design Process (IDP).

Explore: Teams start by working together to come up with different ideas for a platform design. Students then work individually to develop one of the ideas by considering tradeoffs, then creating a drawing (Page 4) and calculating cost in their Student Companion.

Explain: Teams meet and each student explains the idea that they developed to their teammates.

Engineer: Students learn to make tradeoffs and use a design matrix (also called a Pugh Chart) to choose the best solution. With some coaching from the teacher the students create a Design Matrix to compare the ideas developed by individual students and compare each idea against the criterion and constraint of the problem. Once they have made a decision, they ask the teacher to approve the design, and obtain the supplies listed in the Bill of Materials.

Enrich: Students construct the platform that they designed, making improvements as needed when they see how well it works and run into problems.

Evaluate: Encourage the students to redesign and rebuild their platforms if they run into problems. They should also check to be sure their design meets the criteria and constraints of the problem.

Assessment: It is not sufficient for students to build stable platforms. Examine their use of the bill of materials, design matrix, and their understanding of tradeoffs by listening to conversations and examining their responses to questions at the end of the lesson.

KSB3. Hydroponics Laboratory

Aeroponics and Ebb and Flow Systems


Courtesy of Jake Cogger
Aeroponics


Courtesy of Steve Haner
Ebb and Flow

Overview (Days 11, 12, 13, 14, 15)

Students work in teams to design and build **aeroponic** systems in which the plant roots are suspended in a chamber, which is constantly misted with nutrient-rich solution, and **ebb and flow** system in which the plants are placed in cubes of an absorbent material. A separate version of this KSB is provided for students designing and building each of these systems.

Lesson Duration: Five 45-minute periods

Big Idea: Systems have parts that work together to achieve desired results.

Learning Activities

Engage: Divide students into six groups. Assign three groups to design and build an aeroponics system and the other three to design and build an ebb and flow system. (Smaller classes may have fewer groups and larger classes more groups.) Hand out KSB3 (print or online), to guide students in designing and building those systems. Explain that there are no detailed building plans—they are to figure out what to do with the parts and build a system like that shown in their Student Companion.

Explore: Students explore the materials and discuss how they should build the system. They do not drill holes at this point, but they begin to sketch their ideas for how the systems would go together.

Explain: As the student teams finish their plans, they show them to the teacher and explain how the system will function. When the teacher is satisfied he/she will give permission to get tools and begin building.

Engineer: Students construct their systems. As they drill, cut, and assemble the pieces, they continually refer to their plans, and revise as necessary.

Enrich*:* The students test their designs with water, and redesign to fix any leaks.

Evaluate: Students review each other's systems to see how they are similar and different, and how well they appear to meet the requirements of the system they are building.

Assessment: Part of the assessment for this KSB is the quality of the systems. Check to see if they are stable, functioning systems. Also check students' explanations of how the systems work in Check Your Understanding questions. Finally, discuss with the class their responses to questions about the big idea of systems.

KSB4 Hydroponic Farming

Courtesy of Korbin Shoemaker
Harvesting lettuce from hydroponics

Overview (Days 16 through the end of the unit)

In KSB4 students mix the nutrient solution, place seedlings in their hydroponic systems, and set timers. They then monitor their hydroponic systems two or three times a week and record data, such as plant height, color, and number of leaves, as well as quality of the water and temperature and humidity of the air. Students adjust the chemistry of the nutrient solution as needed, and replace the solution completely every two or three weeks. Since monitoring the systems does not take very much time, the rest of the class period will be spent on KBS5, in which students learn CAD and the Grand Design Challenge. Finally, they graph the data and harvest the food.

Big Idea: Feedback involves monitoring and adjusting a system to maintain a desired output.

Learning Activities

Engage: Explain to the students that from now on they will be both agricultural engineers and farmers, tending their crops and using scientific measurements to provided feedback to help them determine what the plants need to maintain healthy growth.

Explore: The students test their systems with plain water first to be sure they function. They then read the instructions on the nutrient solution package, mix the solution and start their systems. They also adjust lights and set timers, then place seedlings in cups and Rockwool cubes.

Explain: The teacher introduces the process of monitoring the systems as a feedback process, such as the kinds of measurements doctors do to maintain human health, and making sure people have good nutrition and exercise.

Engineer: Maintenance is usually the work of a technician, while design is the work of an engineer. Every now and then ask the students to think about the monitoring process. How could it be improved? Encourage students to make note of their improvements to the monitoring process.

Enrich: Students take measurements two or three times a week, learning how to maintain their systems, and how to troubleshoot problems.

Evaluate: It is important not to hang the success of the project on production of a healthy crop; although that is a good goal for the students. Success involves taking regular and accurate measurements, learning what those measurements mean, and taking action to maintain a healthy environment for the plants.

KSB5 *Modeling With Computer Aided Design (CAD)*

Courtesy of Fredesignfile.com. Creative Commons.

Overview (Days 18, 19, 20, 21, 22)

Students learn to use Computer Aided Design (CAD) software on a simple project, to develop their skills in preparation for the Grand Design Challenge later in the unit. A middle school teacher produced a series of five video tutorials to show students how to use Google SketchUp, a free software program that will work on a wide variety of computer platforms. However, other CAD software can be used instead. At the end of the lesson students create a 3D model of an apartment building, which they will later use to demonstrate their solution to the Grand Design Challenge.

Lesson Duration: Five 45-minute periods

Big Idea

A 3D computer model is a realistic representation of a design that can be changed and manipulated.

Learning Activities

Engagement*:* Discuss the different 2D drawings of apples on page 2, and how the drawings might be useful for different purposes. Use this discussion to introduce 3D modeling using CAD. Show a short video about CAD and describe its advantages over drawing.

Exploration: Students use one or two of the five tutorials to learn how to use SketchUp (or another software package.

Explain: Discuss with students that there is still an important place for hand drawing, using the table on the bottom of page 3 to help them think about when CAD is better and when hand drawing is better. The students should also appreciate that a CAD model is more than a drawing that can be changed easily. It allows the user to make and test predictions, such as where shadows will fall at different times of day.

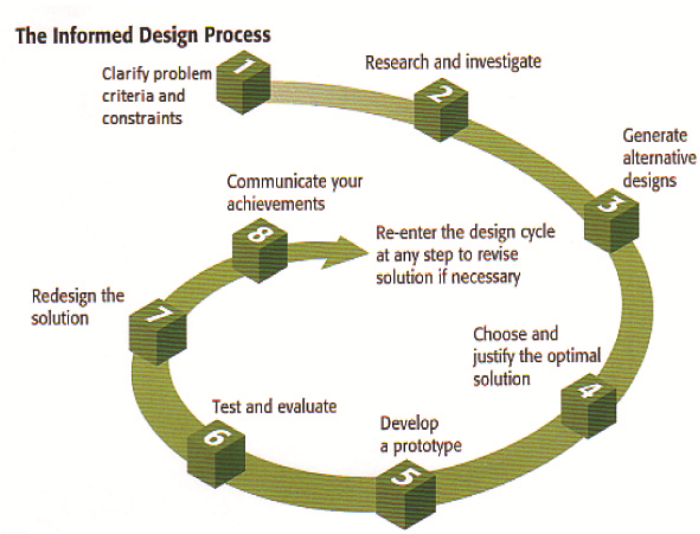
Engineer: Students continue through the rest of the video tutorials, working in pairs to check each others' understanding, using the checklists in the Student Companion.

Enrich*:* Students design and build a model of a large apartment building.

Evaluation: Students critique their own and the teachers' building models using a score sheet.

The Grand Challenge (Days 23 through the end of the unit)

The Design Journal guides students through the informed design process, shown in this image, to meet the Grand Challenge posed by their client—The Community Council.



Stage 1: Clarify Problem Criteria and Constraints (Day 22). The students receive a letter from The Community Council asking for their help. The Grand Challenge is to create a vertical farm design using a 3D modeling program, and demonstrate an operating hydroponic system. Students learn about the informed design process and define the problem in terms of criteria and constraints.

Stage 2: Research and investigate (Day 23). Student teams review what they learned in the KSBs. Then they survey friends in class to see what kinds of fruits and vegetables they like best.

Stage 3: Generate Alternative Designs (Estimate Days 24, 25, 26, 27). Students work in pairs or as individuals to create CAD models of different designs for vertical farm, using the building model they constructed in KSB5 as the foundation.

Stage 4: Choose and Justify the Optimal Solution (Day 28) Teams use a Decision Matrix to evaluate different design ideas against criteria and constraints, and decide on the best idea.

Stage 5: Develop a Prototype (Day 29, 30). Student teams make slight revisions in the 3D model if needed and draft a presentation (e.g. poster or PowerPoint) to show their design to another team.

Stage 6: Peer Review (Estimate Days 31) Pairs of teams to present their ideas and give and receive suggestions for improvement.

Stage 7: Redesign the Solution (Day 32) Teams revise their vertical farm designs based on feedback from the other teams and prepare a presentation for the entire class (their client).

Stage 8: Communicate Your Achievements (Day 33, 34,35) Teams present their final design. Presentations illustrate the trajectory of development, including designs that were not selected and why, feedback on the final design, and modifications. Presentations need to show how the design meets the criteria and constraints of the problem. Students evaluate each other's designs in terms of who well they meet the client's needs.

Summary of the Big Ideas in the Unit

KSB 1 Sustaining the supply of food is a great engineering challenge, especially as the world's population grows.

KSB 2 The Informed Design process uses knowledge and skills to solve problems rather than just trial-and-error.

KSB 3 Systems have parts that work together to achieve desired results.

KSB 4 Feedback involves monitoring and adjusting a system to maintain a desired output.

KSB 5 Models are a powerful means for analyzing and predicting the behavior of systems.

Grand Challenge

Vertical farming is a bold and innovative design concept to provide healthful food in urban environments. Like all new technologies a vertical farm must:

- Meet the needs of people and the environment.
- Make best use of resources, including money, tools and materials, energy, information, and people.

Pacing Guide

The amount of time spent on each lesson and overall length of the unit will vary depending on your student and schedule. The following pacing guide may be helpful for some teachers.

Suggested Pacing Guide (Based on five 45-minute periods per week)

Knowledge & Skill Builders	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
First Four Days	XXXX						
KSB 1 Welcome to Hydroponics	X	X					
KSB 2 Design a Platform		XXXX					
KSB 3 Design Hydro Systems			XXXXX				
KSB 4 Hydroponic Farming				XXXXX	XXXXX	XXXXX	XXXXX
KSB 5 Create 3D Models				XXX	XX		
Grand Design Challenge							
Stage 1 Clarify the Problem					X		
Stage 2 Research and Investigate					X		
Stage 3 Alternative Designs					X	XX	
Stage 4 Choose the Best Design						X	
Stage 5 Develop a Prototype						XX	
Stage 6 Test and Evaluate							X
Stage 7 Redesign the Solution							X
Stage 8 Communicate							XXX

Hydroponic Tips from Korbin Shoemaker

Walkersville Middle School, Walkersville, MD

Test the Water Before You Start

One of the most useful tools you can have for a successful hydroponics classroom is a TDS meter that costs about $15 dollars. TDS stands for Total Dissolved Solids, so it measures the concentration of solids in the water, including the concentration of nutrients that your students will be adding to the water intentionally.

In KSB4 students learn to test and adjust the pH level of their nutrient solutions. You can also teach your students how to use the TDS meter. I explain what it measures and help them decide what to do as a result of a measurement. As you'll see below it can get a little complicated.

Even before you begin the hydroponics unit, start by measuring the tap water that you will be using to fill the hydroponic systems. Pure distilled water is 0 parts per million (ppm). In my tests, bottled water is under 50 ppm. The EPA recommends that drinking water should contain no more than 500 ppm, as well as specific guidelines about which contaminants are okay in different concentrations and which are not.

Plants need different TDS ppm ranges depending on their size and if they are fruit or not. If you're not sure what ppm level your plants need, it is best to start with a lower concentration and increase the concentration if the plants are growing more slowly than you expect. I use the linked chart from Home Hydro Systems

Before going on I should point out that TDS can be measured in different units, just as temperature can be measured in °C or °F. Industry uses electrical conductivity factor (CF) instead of ppm. I prefer ppm because it has more physical meaning for the students. So I use a TDS meter that measures in ppm.

Now back to checking your tap water. If you are growing lettuce (or most plants) and the TDS is higher than 350 ppms, you will likely need to do what I've had to do in my classroom—get a filter. I use a reverse osmosis filter, which is available at most hardware and hydroponic stores.

To get familiar with how the pH and TDS interact start with one gallon of fresh water and add one teaspoon (tsp) of liquid nutrient. Use the meter to see how that changes the TDS. Then add 2mL of pH Up solution, and use the meter again. You'll see that every time you add solutions to the water, the TDS level will increase. Here are some typical results from my classroom. You can see from this example why I filter the water. If I did not the ppm levels would be too high for the health of our plants.

Filtered Water	pH	ppm	Unfiltered	pH	ppm
1 gallon of filtered tap water	5.4	20	1 gallon unfiltered tap water	7.0	380
Add 1 tsp liquid nutrient	3.8	410	Add 1 tsp liquid nutrient	6.4	770
Add 2 mL of pH Up solution	6.0	440	Add 2 mL of pH Up solution	6.0	780

Throughout the growing process students use the TDS meter to monitor the condition of their reservoirs, especially after adding nutrients to make sure we are in the proper range for the plants we are growing. If too high, we add more water to lower the PPMs or concentration of nutrients. If too low, we add more nutrients and increase the concentration.

Even if students do not add pH Up or Down solution to keep the pH in the proper range, ppm will increase as water evaporates, or as plants take up more water, and the solution becomes more concentrated. The TDS level will decrease as plants take up more of the nutrients from the water. So if the water level has dropped due to evaporation, use your meter to measure ppm. If ppm is low, the plants have been absorbing a lot of the nutrients, so mix additional nutrient solution to restore the water level. If ppm is high, then add fresh tap water (filtered if necessary).

Courtesy of Korbin Shoemaker

Using the TDS meter to measure ppm

I also use the meter for troubleshooting. When plants are not looking healthy or die, I check the ppm of the troubled system as well as the other systems to see if the problem is due to the solution or something else.

In summary, the TDS meter is a very powerful tool, both for growing healthy plants and for showing students the value of collecting relevant data. In KSB4 students will find a place to record ppm on their data chart, next to pH.

Electrical Outlets

A number of electrical connections will be needed for each hydroponic system: pump, lights, two timers (one for lights and one for the pump), and in the case of the ebb and flow system, an additional pump to aerate the nutrient solution. Before ordering supplies it is a good idea to take inventory of the electrical outlets around the room, and to determine if they are all on one circuit, so you do not overload the electrical system.

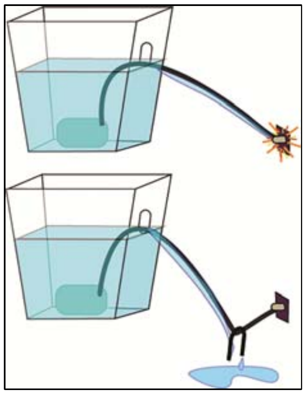
If you can spread out the hydroponic systems around your room, than normal surge protectors should be sufficient. However, if all systems are close together, there may not be enough outlets, and timers can cover up multiple outlets. One solution is to use 4-ft. power strips.

A Kill-A-Watt meter can be used to monitor electricity usage to make many other curricular connections.

Electrical Safety notes

Hydroponics depends on water, and water is a safety hazard around electrical power. Therefore:

- Hang a "U" or "J" hook on each power cord, so that water cannot run along the cord to the outlet.
- When changing water, unplug the power strip, not just the pumps.
- Use GFI outlets when possible.



Hang a weight on the power cord

Lights

It is important to use special lights for growing plants, since the types of bulbs intended for general lighting purposes do not provide most of their light in the spectrum that plants need for photosynthesis. There are two categories of lights that will work well.

Fluorescent Tubes

LED Array

Fluorescent Bulbs (top). Fluorescent tubes or bulbs for growing plants have been available for many years. The designation "T5" are best for hydroponics. In addition to the more common tubes, T5 bulbs are made for standard bulb sockets. Although the bulbs are more difficult to hang two or more can be attached to an insulation board, so the reflect more light and can be raised and lowered together. In general more 5T bulbs mean faster growth.

LEDs. Arrays of LED lights for growing plants have come on the market in recent years. These include red and blue LEDs that correspond to two peaks in the spectrum that most plants need for photosynthesis. LEDs tend to produce more light for the same amount of electrical energy than fluorescent bulbs, so they are a good choice.

Preventing Leaks

Rubber grommet

Depending on how your students design their hydroponic systems, both the ebb and flow and the aeroponics system may require that tubes pierce the growing chamber below the water line. The best way to prevent leaks is to use the rubber grommets in the recommended parts list. A rubber grommet with a 5/8" inner hole will fit the ½" black hose. They will require drilling a ¾" hole be drilled in the bottom of the growing chamber. I find a step drill bit to be useful for to make the holes in the bottom of the growing chamber.

Step drill bits

Selecting Plants to Grow

Many different plants can be grown hydroponically. We have had especially good luck with lettuce, since it germinates easily and the students do not need to wait for the plant to produce fruits, since the leaves are edible. Some of the teachers have had good luck with mint, basil, and vegetables grown from bulbs, such as onions and garlic. Onion bulbs are sold in "sets," which are packages of 20-40 small bulbs for planting.

Students do not have to plant all the same kind of plant in their growing chamber. They can try two or three different kinds of plants to see how they grow differently, provided they have approximately the same pH and ppm requirements.

Courtesy of Korbin Shoemaker

Growing lettuce and onions

Germinating Seeds

Germination is the step when a seed begins to sprout. Some plants are very quick germinators, other take longer and have unique growing requirements such as temperature; so it's a good idea to check the seed packet or the Internet for specific requirements. (On the next page after next are temperature requirements for a long list of plants that can be grown hydroponically.)

In order for students to start growing plants as soon as they build their hydroponic systems in KSB3, I like to start the germination process during the first week of class, about three weeks before students will be ready to start KSB4 Hydroponics Farming.

In order to avoid disturbing the very young root hairs as little as possible, I germinate seeds in Rockwool cubes or net cups and transfer them the cubs or cups to the hydroponic systems when ready. Here’s the process I use.

1. Soak Rockwool in pH adjusted (5.5-6.5) water and remove.

2. Use a toothpick to poke two or three holes in the Rockwool.

3. Put 2-3 sees in each hole (to increase likelihood of 1 strong germinated seed).

4. Gently close the hole with toothpick so the seeds do not get direct light.

5. Put Rockwool in a sealed clear plastic container or special germination dome.

6. Place the germinating directly under a grow light and monitor daily. Open the container every few days to allow fresh air in.

7. Caution: Do not allow the Rockwool cubes to dry out. In dry climates some teachers prefer to take the germinating seeds home over the weekend. Use a mister if needed.

8. You can transfer the Rockwool cubes into the hydroponic systems when three or more leaves have developed, and/or when roots are emerging from the bottom or sides.

Seeds placed in Rockwool cubes

Containers are covered

Seeds in rock wool in germination dome

Seedlings in germination dome

Four images above courtesy of Korbin Shoemaker

Temperature Conditions for Vegetable Seed Germination in °F

Crop	Minimum	Optimum	Maximum
Asparagus	50	75	95
Bean	60	80	95
Beet	40	85	95
Swiss Chard	40	85	95
Lettuce	35	75	95
Onion	35	75	95
Pea	40	75	85
Pepper	60	85	95
Radish	40	85	95
Spinach	35	70	85
Tomato	50	85	95

Data compiled by J.F. Harrington, Department of Vegetable Crops, University of California at Davis

Changing the Nutrient Solution

Plants produce waste products, which can build up in the nutrient solution. Therefore, nutrient solutions should be changed about every two weeks. Having every group replace their nutrient solutions on the same day can be pretty chaotic if space is tight. It takes about 30-45 minutes to empty the water and mix a new solution. Therefore I have found it helpful to have just two or three groups do this in a class period, so that all of the systems have fresh solutions over a period of two or three days.

On those days have several empty 5 gallon water buckets ready to empty the used solutions and several other 5 gallon water buckets filled with fresh water so time does not have to be wasted filling them up. (10 gallons of water is heavy and easy to spill, so it's best to move water 5 gallons at a time.) The students should mix the nutrients in the buckets before pouring them into the reservoirs.

Tips for Mixing Nutrients

It's challenging to pour a large container of nutrient concentrate into small measuring cups or spoons. One method is to pour the solution into beakers or measuring cups with spouts, and give those to the students to measure when mixing their solutions.

Courtesy of Korbin Shoemaker

An even easier method is to provide the students with cups or beakers of nutrient concentrate and plastic syringes (no needle), which are graduated to measure quantities precisely.

Be sure to have your students read the instructions on the container. Most nutrients require different concentrations for different stages of growth, starting with lower concentrations for seedlings, and higher concentrations for more mature plants.

Measuring Plant Growth

Since different plants grow in different ways, there is no single method that works. For some plants students can count leaves. Others will increase in height. Onion and garlic plants put out long leaves that can be measured. The length, width, and number of lettuce leaves can be measured. Leave these decisions to your students. It's okay if the plants need to grow for a few days or even a week before the students settle on a method. It will be easier for them to analyze the data if they choose a single measurement. Also measuring in millimeters is easier than measuring in inches as students do not need to deal with fractions.

Courtesy of Korbin Shoemaker

Troubleshooting

Not all plants will thrive, even if the nutrient solution is perfect. This in itself is a good lesson. However the lesson will be even better if you can help the students figure out what is wrong. The use of pH and TDS for troubleshooting is mentioned above. Here are some other things to check:

Temperature of the water: Especially on very hot or very cold days temperature could cause problems. In that case see if there might be a different location in the room that might provide a better environment.

Temperature of the air: For most plants air temperature should be between 65°F - 85°F. In schools we often don't know what the temperatures are like at night or on weekends, so that requires some investigation when starting out. If too high or too low try adjusting the thermometer in the room or change the height of the light. A fan can also be helpful in reducing air temperature.

Humidity: Plants can dry out if the humidity is too low. Ideal greenhouse conditions are between 50% and 80% humidity. Although there may not be much you can do to change this level, it may at least be helpful to know the cause of a problem.

Water depth: Mark a wooden dowel with centimeter increments. Dip it into the reservoir a couple of times per week to measure depth. The pump should be covered with at least one inch of water. Also, knowledge of water depth will help you explain changes in pH or ppm, and provide further information about the condition of your plants.

— Korbin Shoemaker

Choosing plants. As Korbin Shoemaker explained in the previous section, there are three ways of starting plants: from seed, from bulbs, and from cloning (also called "cuttings.") Some of our pilot teachers have had good luck with germinating seeds for lettuce, kale, mint, basil, and other leafy greens. Other teachers who had difficulty germinating plants from seeds had success planting onion bulbs. Hydroponic experts recommend cloning. So as far as we have been able to determine, all of these methods work. You may want to go to your local nursery to see what kinds of seeds and bulbs are available. One teacher went to the grocery store to purchase a whole basil plant to make clones. It's a good idea to use a small number of different varieties and see what works best for your local growing conditions.

Vegetable Seeds

Onion Bulbs

Clone

Teams

Each team will develop one hydroponic system, either aeroponics or ebb and flow. Pilot teachers had three of each type of system in their classrooms, for a total of six teams, so that students could see two types of systems in operation, but ordering equipment was not too complicated.

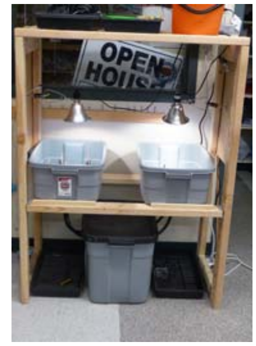
To order supplies you will need to know how many teams of students you will have. Deciding on the number of students per team involves a tradeoff between keeping the number of students small, so that they will be more engaged, and keeping the number of teams small to contain equipment costs, classroom space, and presentation time near the need of the unit. As a general guide, it is best for teams to include no more than 4 or 5 students.

Materials

Platforms

You will also need to decide between wood or PVC tubes for building platforms. PVC pieces fit in many different ways, and can be re-used many times. Wooden 2' x 4's offer the opportunity for students to learn woodworking skills. Purchasing PVC locally costs about the same as purchasing it online and paying for shipping.

Courtesy of Korbin Shoemaker
PVC Platform



Courtesy of Steve Haner
Wood Platform

Per Team	Qty.	Source	Part Number	Item Description (PVC Option)	Item Cost	Total
0.5	2.0	Lowes	#: 23993	Charlotte Pipe 1" 200PSI SDR 21 PVC pipe - 10ft	2.81	5.62
4	16.0	PVC*	1" 3-WAY FURN SIDE ELBOW	1" 3-WAY FURNITURE FITTING - SIDE ELBOW	0.94	15.04
6	24.0	PVC*	406-010	1" Sch 40 PVC 90 Elbow	0.34	8.16
4	16.0	PVC*	1" 4-WAY FURN SIDE OUTLET TEE	1" 4-WAY FURNITURE FITTING - SIDE OUTLET TEE	1.14	18.24
4	16.0	PVC*	401-010	1" Sch 40 PVC Tee	0.45	7.20
6	24.0	PVC*	429-010	1" Sch 40 PVC Coupling	0.27	6.48
						60.74

* Refers to PVC Online. PVC straight tubes can be cut before class into a variety of 6", 12", 18", 24" and 36" lengths.

Per Team	Qty.	Source	Part Number	Item Description (Wood Option)	Item Cost	Total
2	8.0	Home Depot	#6006	Whitewood Stud 2"x4"x96"	2.62	20.96
1	1.0	Home Depot	Item: 17365	Grip Rite 1lb #8 x 2.5" Deck Screws	0.94	0.94
						21.90

Hydroponic Supplies

Some supplies can be purchased at Do It Yourself (DYI) stores, like Home Depot or Lowes. Hydroponic supplies can be purchased at specialized stores in most large cities or over the Internet. Other supplies can be purchased locally at hardware stores. Following is a list of materials that you will need for one aeroponics system and one ebb and flow system. You will need to multiply by the number of teams in your class(es). Following is a shopping for hydroponics supplies.

Hydroponics Equipment for Six Teams (3 Aeroponics, 3 Ebb and Flow)

Per Team	Qty.	Source	Part Number	Item Description	Item Cost	Total
1	4.0	DIY Store	SKU # 383321	Roughneck 18 Gallon Tote	6.97	27.88
1	4.0	DIY Store	SKU #489754	Roughneck 10 Gallon Tote	7.97	31.88
1	4.0	Amazon	AAPA3.2L	Air Pump 3.2L	10.46	41.84
1	4.0	Amazon	B00S2DPYQM	Erligpowht 45W Indoor Grow Light	27.99	159.96
1	4.0	Amazon	B00FA7A8QY	Hydrofarm 15 minute Grounded Timer (for Pump)	14.99	59.96
0.5	2.0	Amazon	B00O3H03LW	Instapack Grounded 24 Hour Timer (2 pack) (for Light)	14.99	29.98
1	4.0	Amazon	B00B2CZTJW	Jebao PP388 High Volume Submersible Pump AERO	18.99	75.96
0.5	2.0	Amazon	B00520AR9C	Lexan sheet 18"x24"	18.67	37.34
1	4.0	Amazon	B00L77655Y	CNZ Blue Stone Bar (2 pack)	5.29	21.16
1	4.0	Amazon	B0002563MW	Penn-Plax Air Line Tubing	4.65	18.60
1	4.0	Amazon	B00IGFDTSQ	Gro Top Hat rubber grommets 10pk	6.95	27.80
	1.0	Organica	708660	1/2" ID Black Tubing (NOTE NOT OD) - 25FT Length	10.95	10.95
0.5	2.0	Organica	AAST50	1/2" Stopper - 10 pack	6.95	13.90
2	8.0	Organica	BCFTBKKT	1/2" Bulkhead Barbed Fitting	9.95	79.60
2	8.0	Organica	AAEL50	1/2" Barbed Elbow	0.95	7.60
2	8.0	Organica	AAT50	1/2" Barbed Tee	0.95	7.60
1	4.0	Organica	PBV210	1/2" Barbed Shut-off valve	4.95	19.80
5	20.0	Organica	EZCSPJ	ez Clone 360 Misting Nozzles **MUST BE RED TYPE**	0.75	15.00
0.5	2.0	Organica	GH1515	pH Test Kit 1oz	7.95	15.90
5	20.0	Organica	GH6601	2" Net Cups	0.30	6.00
1	1.0	Organica	GMC10L	PlantIt Clay Hydroton 10L 8-16mm	11.95	11.95
3	3.0	Organica	RWDM4G	Rockwool 3"x3"x2.5" 8-pack	6.50	19.50

Hydroponics Equipment to be Shared by All Teams

	1.0	Amazon	B004NJTYQA	CTT 13 Pc Hole Saw Set	13.84	13.84
	1.0	Amazon	B001OEPYWK	Meiko Step Drill Set (3/16"-3//4")	11.30	11.30
	1.0	Amazon	B000VTQM70	HM Digital TDS-3 Handheld TDS Meter	15.96	15.96
	1.0	Organica	DYNRO100	Dyna-Gro 1gallon	55.95	55.95
	1.0	Organica	708660	1/2" ID Black Tubing (NOTE NOT OD) - 25FT length	10.95	10.95
	1.0	Organica	GH1532	pH Down Acid Liquid Quart	11.95	11.95
	1.0	Organica	GH1522	pH Up Base Liquid Quart	11.95	11.95
				Grand TOTAL		**861.11**

Most of the above materials can be used more than once. Following is a list of consumable supplies that can be used for a new class. Prices and sources will change over time. See KSB3 and KSB4 for images of these materials. These are pictured in KSB3A, KSB3B, and KSB4.

Replenishment Materials Needed to Repeat the Class

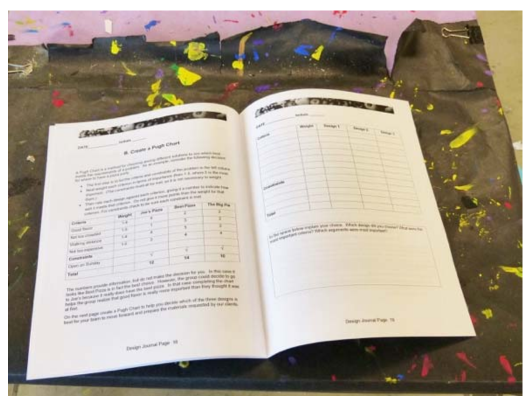
Per Team	Qty.	Source	Part Number	Item Description	Item Cost	Total
1	6	DIY Store	SKU #489754	Roughneck 10 Gallon Tote	7.97	31.88
0.5	2.0	Organica	GH1515	pH Test Kit 1oz	7.95	15.90
5	20.0	Organica	GH6601	2" Net Cups	0.30	6.00
1	1.0	Organica	GMC10L	PlantIt Clay Hydroton 10L 8-16mm	11.95	11.95
3	3.0	Organica	RWDM4G	Rockwool 3"x3"x2.5" 8-pack	6.50	19.50
1/Class	1.0	Organica	708660	1/2" ID Black Tubing (NOTE NOT OD) - **25FT LENGTH**	10.95	10.95
				Total		**146.51**

Useful Tools

Hole Saw Set Step Drill Set Cordless Drills	**Tubing Cutter Shears** **Scissors Drill Index** **Small Files and Rasps**	**Extension Cords** **Power Strips** **Measuring Tape**	**Marking Pens**

Student Companion

Materials to guide student work are in the form of separate word files for each KSB. They can be provided to students in print or online. The materials should be handed out one KSB at a time. There are places in the *Student Companion* for students to write or draw. If students have access to computers they can be provided as editable computer files; or the materials can be printed and handed out in class. As shown at the right, one of the micro-test teachers sent the files to the district's print shop that made 8 ½ " x 11" booklets of each KSB.



Steve Haner

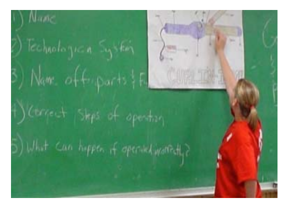
Printed Version of Design Notebook

The 6E Instructional Model

The 6E instructional model, summarized below, permeates the Engineering for All units. Although each day's instruction does not necessarily include all six stages of the model, each lesson generally includes these instructional procedures in roughly the same order. The following summary is drawn from an article that appeared in the March 2014 issue of *The Technology and Engineering Teacher*. The complete article can be found in the Appendix to this Teacher Guide.

Engage The purpose of the ENGAGE phase is to pique student interest and get them personally involved in the lesson, while pre-assessing prior understanding. During this experience, teachers present the instructional task to their students. They also make connections between past learning experiences (prior knowledge), setting the organizational groundwork for upcoming activities. The purpose is to stimulate students' curiosity and encourage them to ask questions.

Explore is the period where students get directly involved with phenomena and materials. As they work together in teams, students build common experiences that prompt sharing and communicating. The teacher acts as a facilitator, provides materials and guides the students in problem solving, making hypotheses, testing their predictions, and drawing conclusions.



Explain is the phase during which teachers encourage learners to begin to communicate what they have learned. Language provides motivation for sequencing events into a logical format. Communication occurs between peers, with the facilitator, and through reflection and *Socratic Questioning*. The teacher may also explain concepts and phenomena, helping to correct misconceptions observed during the earlier phases.

Engineer is the phase of learning where teachers help students integrate scientific inquiry and engineering design to make more informed decisions. Teachers will focus on the EfA themes of design, systems, modeling, resources, and human values as the basis for development, construction, refinement, assessment, and redesign.

Enrich is the phase during which learners can transfer understanding and purpose to new situations and applications. They understand and are able to utilize concepts relating to **Design, Modeling, Resources,** and **Systems** and apply them to Human Values in ways that enrich their understanding and their ability to transfer learning to new situations and problems.

Evaluate The final "E," is an ongoing diagnostic process that allows the teacher to determine if the learner has attained understanding of concepts and knowledge. Evaluation and assessment is not linear and should occur during all phases of instruction.

Above images courtesy of ITEEA

Assessment and Grades

The purpose of the KSBs is for the students to acquire knowledge and skills that they will later need to meet the Grand Design Challenge. Each KSB has also been designed to teach an important idea about engineering design, called the Big Idea. Each KSB ends with a section called "Check Your Understanding" and "What's the Big Idea." Students' responses to these sections provide information on their understanding of the ideas from the KSB. However, the most important method for assessment will be to observe the students during class and listen to their conversations to see the extent to which they understand the concepts, develop the skills, and maintain interest in the project. The Grand Design Challenge asks each student to submit their Design Journal at the conclusion of the project for scoring with a rubric. You can use the students' responses to the questions at the end of each KSB and the scores on the rubric at the conclusion of the GDC as a source of data for grades if that is consistent with your school's policies. We have chosen not to provide additional tests so as to maintain focus on what the students do during each KSB and the Grand Challenge.

Consistent Features of Each KSB

Big Idea. One big idea about engineering is emphasized in each KSB and the Grand Challenge. It is these ideas that we would like our students to remember and apply in the future.

Learning Goals. These are written for students in the KSBs, beginning with the phrase "I can…" Connections between the learning goals and standards are provided in the KSB section of this Teacher Guide.

Think Like an Engineer. This feature invites students to view the subject matter in a way similar to how an engineer might think about this question or issue.

Points to Ponder. This feature stimulates student thinking. For example, many people have difficulty understanding how hydroponics functions, since they are used to seeing plants growing in soil. But few people think about what soil provides, or the importance of carbon dioxide in the air as a source of carbon for plants to grow. This feature is intended to raise such questions.

Check Your Understanding. This feature enables students to reflect on what they've learned and can serve as embedded formative assessment opportunities.

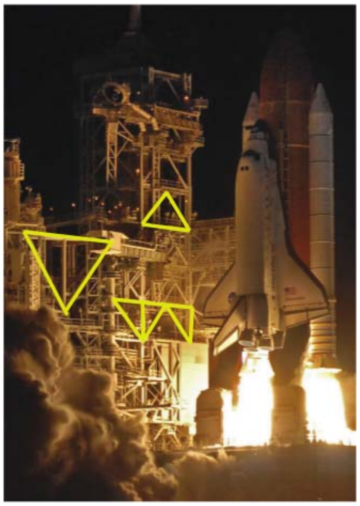
What's the Big Idea? Asks students to reflect on the big idea presented on the first page.

Safety is of paramount importance to every classroom. While this guide contains some general safety guidelines, it does not address specific tools, equipment, or working spaces. Teachers must provide comprehensive safety guidelines to students based upon individual classrooms. General safety guidelines should include:

1. Students use tools and equipment safely, maintaining a safety level for themselves and others in the laboratory-classroom.
2. Students demonstrate respect and courtesy for the ideas expressed by others in the class.
3. Students show respect for and appreciation of the efforts of others.

These safety notes apply to every KSB and phase of informed design, whether or not tools are involved.

First Four Days (Introduction to Engineering for All)



NASA, Public Domain

Overview (Days 1-4)

Like all projects in the Engineering by Design series, the unit is launched by an introductory lesson called The First Four Days. The students first do a short activity to "Build The Tallest Tower," without instruction. They then learn how to design stable structures, guided by the eight steps of the Informed Design Process. They then apply the Informed Design Process to the subsequent unit, Vertical Farms: Fresh Food for Cities.

Big Idea: Engineering aims to benefit society and the environment and is accomplished through collaboration and problem solving.

Lesson Duration: Four 45-minute periods (Days 1, 2, 3, and 4)

Standards and Learning Goals

Standards	Learning Goals
NGSS MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. NGSS Crosscutting Concepts: Structure and Function; Influence of Science, Technology and Engineering on Society and the Natural World. STL 9 Students will develop an understanding of engineering design. STL 11. Students will develop the abilities to apply the design process. EfA Theme: Design	1. I can give an example of how engineering benefits society and the environment. 2. I can explain how using a systematic process to solve a problem is more likely to result in a good solution than using a trial and error approach. 3. I can work well with others to solve a problem.

Vocabulary

Engineering: Creating or improving technologies to solve problems and meet peoples needs or wants.

Criterial: Qualities of a successful solution.

Constraints: Limits.

Human values: Convictions and beliefs that guide daily life.

Tools/Materials/Equipment

For constructing towers

Tools and materials will vary widely depending on what you have available. Most common tools and materials used for this activity are used paper and tape, and scissors. Teams will also need one golf ball or equivalent. These may be put into paper bags and given to teams.

For experimenting with shapes

5-6 plastic straws

10-12 paper clips

Safety

Safety issues may involve use of sharp tools. Remind students that this is a laboratory, and playing with tools is not allowed.

Learning Activities

Engage: Students are given a bag of supplies and told to "build the tallest free-standing tower that you can that will support the weight of golf ball for at least two minutes." Teams are allowed 20 minutes to plan and build. They are not given any instruction about the Informed Design Process at this point.

Explore: Students explore the materials, and then build their towers. Towers that hold the weight of a golf ball for at least two minutes are measured and a "winning team" is declared.

Explain: The teacher presents the Informed Design Process, commenting on the difference between the trial-and-error approach the students just completed and engineering guided by the Informed Design Process. Student teams then undertake a series of short activities in which they construct and test squares, diamonds, and triangles made from paperclips and straws. The activity concludes as students explain what they learned about the stability of various shapes.

Engineer: Students are asked to "Think Like an Engineer" and redesign their towers using the same materials; but this time applying the knowledge they caned from the activities with shapes and the Informed Design Process.

Enrich: Students view images of bridges, towers and other full scale structures, so they can see the connection between their activity and how professional engineers build structures that help society.

Evaluate: Students are asked to reflect on the Big Idea, and how it relates to the activities that they just completed. The lesson concludes with a few broad questions about the value of the Informed Design Process in daily life, and the skills that the students will need to become better at solving problems.

Products

The products that students produce in this KSB is the two towers—one made with a trial-and-error approach and one made with the Informed Design Process. Differences between the two may or may not be evident. What is important is that students recognize that the second approach is much more systematic and thoughtful, and in most cases is likely to lead to a more productive outcome.

Assessment

The most important outcome of this KSB is for students to learn about the purpose and process of engineering. Their responses to questions 1 and 2 on page 8, should indicate that they understand that the aim of engineering is to benefit society and the environment and is accomplished through collaboration and problem solving. They may also learn that engineering is systematic problem-solving. Their response to question 3 might list skills such as understanding people's needs, being creative, and working well with others.

Answer Key

Page 4

1. The square collapses to the side (shear).
2. The diamond also collapses to the side
3. The triangle keeps its shape.
4. The triangle is the strongest and most stable shape.
5. Large structures should be strengthened with triangles.

Page 5

Step 1. Define the Problem.

Statement of the Problem: Build the tallest tower possible without tying it down with tape or anything, and using just the materials we were given.

Criteria for Success: The tower holds a golf ball at least two minutes. It is as tall as possible.

Constraints: We can use just the materials you have given us. It has to be done by (the time the teacher specified.)

Step 4. Choose and Justify the Optimal Solution.

Students should have a good reason for their decision.

Page 6

Step 6. Test and Evaluate Your Design.

Students should be able to explain how the new tower differed from the prior tower.

Step 7. Redesign the Solution.

Students should be able to discuss at least one improvement they could make.

Step 8. Communicate Your Achievements.

Students list what they have accomplished, what they learned, and what other teams told them about their design.

Page 7

1. Strong and stable structures help people meet their needs and stay safe. Good engineering should also use minimal resources so as not to harm the environment.

2. Answers will vary.

3. The tower consists of parts that are all connected to each other. If one part is removed or breaks the entire tower will collapse.

4. It is much less expensive and safer to test a model than to test a full scale structure.

KSB1. Welcome to Fresh Food Engineers

Cary Sneider

Overview (Days 5, 6)

Students are informed that they have been hired to work in a small engineering company that specializes in hydroponic systems design. One day they will be asked to design a large vertical farm, but first they need to learn about hydroponics and CAD. The KSB then introduces students to the need to feed a rapidly growing population, the pros and cons of hydroponics for solving the food problem, and describes four different hydroponic systems.

Big Idea: Sustaining the supply of food is a great engineering challenge, especially as the world's population grows.

Lesson Duration: Four 45-minute periods

Standards and Learning Goals

Standards	Learning Goals
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 NGSS Crosscutting Concept: Science, technology, and engineering influence society and the natural world. STL 15. Students will develop an understanding of and be able to select and use agricultural and related biotechnologies. EfA Theme: Human Values	I can: 1. Explain how "food deserts" impact people who live in low-income neighborhoods. 2. Explain that increased population and reduction in fresh water and land suitable for farming put the world's food supply at risk. 3. Define hydroponics and explain how some representative hydroponic systems function. 4. Make a case for how hydroponics can help provide fresh food for people in cities.

Vocabulary

Hydroponics: A method of growing plants in a water (hydro) solution, without soil.

Agricultural Engineer: A person who develops new and improved technologies for growing an processing food.

Food Desert: A low-income community located more than a mile from a source of fresh fruits and vegetables.

Vertical Farming: Using tall buildings to grow food.

Sustainable Development: A way to meet the needs of the present without sacrificing the needs of future generations.

Aeroponics: A hydroponic system in which the plant roots are suspended in a chamber, which is constantly misted with nutrient-rich solution

Ebb and Flow: A hydroponic system in which the plants are placed in cubs of an absorbent material (Rockwool) and a nutrient-rich solution is pumped into the chamber and then drained periodically

Tools/Materials/Equipment

- Projector
- Computer
- You Tube Video
- Student Companion, KSB1 for every student (online or printed)

Safety

No relevant safety issues in this KSB.

Learning Activities

Engage: Hand out KSB 1 (or open on computer or tablet). Ask the students to imagine they have just been hired as an engineer, working for a company called Fresh Food Engineers, Inc. Explain that the purpose of the company is to help people who live in cities in the U.S. and around the world have access to fresh, nutritious, and affordable foods. Discuss the idea of *food deserts*, pointing out that in many low-income neighborhoods in the U.S. people have difficulty obtaining affordable fresh fruits and vegetables, which leads to poor health.

Explore: Have students access the U.S. Department of Agriculture's Food Access Research Atlas on the Internet. The assignment is for students to zoom in on the area where they live, or other areas they know personally, and use the key to see if it is a food desert (Page 2).

Discuss with students the global problem of feeding a growing world population with dwindling land and water supplies suitable for farming (Page 3).

Explain: Introduce the idea of vertical farming by having students read about it in KSB1 (Page 4), and/or by having them research the concept on the Internet and report their findings. Buildings constructed for vertical farming have been designed, but it is expensive to construct new buildings in cities. However, growing food on the surface of existing buildings is a very promising idea.

Explain that the students' grand challenge will be to design such a vertical farm. First, however, they will need to learn to grow foods hydroponically and learn to use Computer Aided Design.

Have the students read "What Do Plants Need?" (Page 5) and discuss the rather surprising idea that plants do not get most of their mass from the soil or nutrient solution—but rather from the air! Plants take in carbon dioxide and, with the help of energy from sunlight, break it down into carbon and oxygen. They release the oxygen to the air and use the carbon to build stems, leaves, roots, and other plant parts. This means that plants do not need soil to grow. They just need air, sunlight, and water with some dissolved minerals.

Have students read and discuss the concept of hydroponics, and the pros and cons of hydroponics (Pages 6 and 7). Then show the 5-minute video Hydroponic Lettuce, and invite students to discuss their impressions. Explain that as engineers for this company they will be asked for their advice about where hydroponics should be used and where it should not be used. Have them work in pairs to answer the questions on Page 8.

Engineer: Use a video projector to show and discuss the diagrams of the four hydroponic systems (Pages 9-12). Have students research these and other hydroponic systems online.

Enrich*:* Have students search for and view videos about agricultural engineering and vertical farming. Challenge them to find examples in which food is grown on the walls of buildings.

Evaluate: Have the students work individually to complete Check Your Understanding and What's the Big Idea? Then have the students work in pairs to discuss their answers. Facilitate a class discussion, asking students to share what they learned from the KSB, and what questions they may have. Pick up the students' papers to conduct your own assessment.

Products

Completed Student Companion for KSB1

Assessment

Examine students' responses to Check Your Understanding (Page 13, 14), focusing primarily on whether they were able to:

1. Explain how "food deserts" impact people who live in low-income neighborhoods. (Q1)
2. Explain that increased population and reduction in fresh water and land suitable for farming put the world's food supply at risk. (Q2)
3. Define hydroponics and explain how some hydroponic systems function. (Q5, 6, 7, 8)
4. Make a case for how hydroponics can help provide fresh food for people in cities? (Q9)

Read the students' responses to questions in What's the Big Idea? (Page 15). Make a list of any misconceptions or concerns expressed by the students in Check Your Understanding and What's the Big Idea? Plan further discussions or activities to address these. Even if the great majority of students grasp the most important ideas it is a good idea to briefly review for students who may be less confident and to show all of the students that you've read their responses and care what they write.

You may also wish to use the Student Companion to obtain further information on students' understanding and participation. Following is a list of the responses to expect on each page of the Student Companion that asks for students to write.

Answer Key

Following are answers to all of the questions asked in this KSB.

Page 2 Answers will vary depending on what students find.

Page 3 Answers will vary, but should reflect recognition that both fresh water and land are essential for growing food, and that the demand for food will increase in future decades.

Page 4

1. Students may think of ideas such as conserving on consumption of electricity, water, and other resources, or using more sustainable methods of generating electrical energy, such as solar and wind power.

2. Answers will vary depending on students' experiences. Some students may point out that not all engineering is necessarily beneficial (e.g. weapons of mass destruction, pollution from industry, etc.)

Page 5

Top: Students list water, air (or CO_2) and sunlight

Bottom: air (or CO_2) and sunlight

Page 6 Answers will vary.

Page 8

1. Soil farming is less expensive where there is available land and adequate rain.
2. Hydroponics is a better choice in cities where land and water are both very expensive.
3. Answers will vary; but some students may suggest both methods.

Page 9

1. Pump
2. Inflow
3. Outflow
4. Rockwool® cubes

Page 10

1. Through the inflow/outflow tube
2. To prevent the nutrient solution from covering the plants
3. To switch the pump on and off

Page 11

1. In both systems the roots are periodically flooded with nutrient solution.
2. Ebb and flow floods and then drains, while the nutrient flow system channels the solution from one end of the growing chamber to the other.

Page 12

1. The pump must be strong enough to produce a spray.
2. Plants need the carbon dioxide in air to grow.

Page 13 and 14 Check Your Understanding

1. b
2. d
3. c
4. c
5. b
6. a

7. c

8. a

9. Hydroponics takes less space and less water than soil farming, so it is suitable for growing food in cities. Vertical farming would make it possible to grow food on vertical walls, taking up even less space.

Page 15 What's the Big Idea?

There are no right or wrong answers for these questions. However, students' answers should provide some insight into how they think about the most important idea in this KSB.

KSB2. Design and Build a platform

Cary Sneider

Jake Cogger's Class, Salem, OR

Overview (Days 7, 8, 9, 10)

This is a key lesson in which students learn to engineer a product. Students are shown the materials that they will use (either wood or PVC tubes). They are given the challenge of designing a platform that will hold the growing chamber and reservoir, allow for tubes to pass between them, and hold lights that can be adjusted. The teacher guides the students in designing their platform, creating a bill of materials, making tradeoffs, and using a design matrix. Students build their platforms.

Big Idea: The Informed Design process uses knowledge and skills to solve problems rather than just trial-and-error.

Lesson Duration: Four 45-minute periods

Standards and Learning Goals

Standards	Learning Goals
NGSS MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. STL 9 Students will develop an understanding of engineering design. STL 11. Students will develop the abilities to apply the design process. EfA Theme: Design	I can: 1. Us the Informed Design Process to solve a problem. 2. Explain why the Informed Design Process is a better approach than trial-and-error. 3. Make tradeoffs to improve a design. 4. Use a design matrix to choose the best solution to a problem. 5. Use tools competently and safely.

Vocabulary

Criteria: The desirable features of a successful solution to a problem

Constraint: Limits to a solution, usually refers to available materials, budget, and/or time

Tradeoff: A design process in which one feature is sacrificed favor of another feature

Design Matrix: A table in which each solution is scored against criteria and constraints

Bill of Materials: List of all materials and costs for fabricating an object

Tools/Materials/Equipment

As described on page 26, there are two options for building hydroponic platforms: using PVC tubes or wood. Ether option is fine for learning the important ideas in this KSB about how to use the Informed Design Process, including use of a Design Matrix and Bill of Materials. PVC tubes can be reused many times, while wood is less expensive and provides experience in woodworking. Here is list of materials needed **for each team**, for each of those options.

Per Team	Qty.	Source	Part Number	Item Description (PVC Option)	Item Cost	Total
0.5	2.0	Lowes	#: 23993	Charlotte Pipe 1" 200PSI SDR 21 PVC pipe - 10ft	2.81	5.62
4	16.0	PVC*	1" 3-WAY FURN SIDE ELBOW	1" 3-WAY FURNITURE FITTING - SIDE ELBOW	0.94	15.04
6	24.0	PVC*	406-010	1" Sch 40 PVC 90 Elbow	0.34	8.16
4	16.0	PVC*	1" 4-WAY FURN SIDE OUTLET TEE	1" 4-WAY FURNITURE FITTING - SIDE OUTLET TEE	1.14	18.24
4	16.0	PVC*	401-010	1" Sch 40 PVC Tee	0.45	7.20
6	24.0	PVC*	429-010	1" Sch 40 PVC Coupling	0.27	6.48
						60.74

* Refers to PVC Online. PVC straight tubes can be cut before class into a variety of 6", 12", 18", 24" and 36" lengths.

Per Team	Qty.	Source	Part Number	Item Description (Wood Option)	Item Cost	Total
2	8.0	Home Depot	#6006	Whitewood Stud 2"x4"x96"	2.62	20.96
1	1.0	Home Depot	Item: 17365	Grip Rite 1lb #8 x 2.5" Deck Screws	0.94	0.94
						21.90

In addition to the above materials, each team will need:

1 10- gallon tote

1 18-gallon tote

1 copy of the Student Companion (print or online) for KSB2

Safety

If you have not already done so, give your students a lesson on using tools safely, and provide a list of safety rules.

Learning Activities

Engage: Organize the class into six teams. Provide each team with a 10-gallon and 18 -gallon tote. Explain that the smaller tote will be the growing chamber for the plants and the 18-gallon tote will be the reservoir for the nutrient solution that will be pumped into the growing chamber. Tell the students that their task is to design a platform that will hold both parts of the system, and that will hold lights suspended above the plants. Explain why the platform is needed, and the criteria and constraints of the task (Page 2). Introduce the Informed Design Process (IDP) (Page 3).

Explore: Invite the students to examine the materials they can use to build the platform, and provide a list of the cost of the materials. Teams work together to come up with different ideas for a platform design. Students then work individually to develop one of the ideas by considering tradeoffs, then creating a drawing (Page 4) and calculating cost in their Student Companion (Page 5).

Explain: Teams meet and each student explains the idea that they developed to their teammates.

Engineer: Students learn to make tradeoffs (Page 5) and use a design matrix (also called a Pugh Chart) to choose the best solution. With some coaching from the teacher the students create a Design Matrix to compare the ideas developed by individual students and compare each idea against the criterion and constraint of the problem. (Page 6) Once they have made a decision, they ask the teacher to approve the design, and obtain the supplies listed in the Bill of Materials.

Enrich*:* Students construct the platform that they designed, making improvements as needed when they see how well it works and run into problems. (Page 7)

Evaluate: Encourage the students to redesign and rebuild their platforms if they run into problems, and to be sure their design meets the criteria and constraints of the problem. (Page 7)

Products

Each team should construct a sturdy platform that meets all of the criteria and constraints that you specified. Each individual should complete their Student Companion for KSB2.

Assessment

It is not sufficient for students to build stable platforms. Examine their use of the bill of materials, design matrix, and their understanding of tradeoffs by listening to conversations and examining their responses to questions at the end of the lesson.

Examine students' responses to Check Your Understanding (Page 8-9), focusing primarily on whether they were able to:

Question 1-4: Use a design matrix to make a logical choice.

Questions 5-6: Recognize the value of the Informed Design Process.

(See the Answer Key below for specific answers to the questions.)

Read the students' responses to questions in What's the Big Idea? (Page 15). Note what the students like and dislike about using the IDB, and encourage them to discuss their thoughts the next day in class.

You may also wish to use the Student Companion to obtain further information on students' understanding and participation. Following is a list of the responses to expect on each page of the Student Companion that asks for students to write.

Answer Key

Page 2: The questions at the bottom of page 2 are intended to provide feedback to you about whether or not the students heard your message about what materials they can use and when the assignment needs to be completed.

Page 3: Students should provide measurements of how large the platform needs to be, including the clearance between the two totes.

Page 4: Each student should develop one idea, with a sketch and list of the advantages and disadvantages of the is design.

Page 5: Top: Look for one or two tradeoff ideas. **Bottom**: Check the Bill of Materials with the sketch on the previous page, to see if students properly calculated the amount of materials they needed and correctly calculated the cost.

Page 6: Coach students in using the design matrix. Tell them not to award more than five points for each design on each criterion and constraint. At the bottom of the page check to see if the students have explained their decision and the tradeoffs they made.

Pages 8-9. Check students' answers to these questions. Here are the correct answers:

1. c
2. b

3. Because there are rarely perfect solutions, so it is usually necessary to give up some of one desirable quality in order to get more of another quality.

4. Answers will vary.

5. Students should disagree with the statement, which suggests the IDP is a trial-and-error method. Instead it is a systematic way of finding the best solution to a problem.

6. Answers will vary.

7. Answers will vary

KSB3. Hydroponics Laboratory

Aeroponics and Ebb and Flow Systems

Jake Cogger
Aeroponics

Steve Haner
Ebb and Flow

Overview (Days 11, 12, 13, 14, 15)

Students work in teams to design and build **aeroponic** systems in which the plant roots are suspended in a chamber, which is constantly misted with nutrient-rich solution, and **ebb and flow** system in which the plants are placed in cubes of an absorbent material. A separate version of this KSB is provided for students designing and building each of these systems.

Big Idea: Systems have parts that work together to achieve desired results.

Lesson Duration: Five 45-minute periods

Standards and Learning Goals

Standards	Learning Goals
NGSS: 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. NGSS Crosscutting Concept: Systems and System Models STL 2. Students will develop an understanding of the core concepts of technology. (Systems have parts or components that work together to accomplish a goal.) STL 15. Students will develop an understanding of and be able to select and use agricultural and related biotechnologies. EfA Themes: Design	I can: 1. Explain the difference between a system and a collection of parts. 2. Explain how the system that I designed (aeroponics or ebb and flow) functions. 3. Describe the inputs, outputs, and goals of the system I designed. 4. Use tools competently and safely.

Vocabulary

Growing Chamber: Container in which plants grow in a hydroponic system.

Reservoir: Container for holding nutrient solution in a hydroponic system.

Barbed fittings: Hard plastic tube connectors for flexible plastic tubing

Misting Nozzles: Small plastic parts that create a misting spray when placed over the end of a tube with water under pressure.

pH: A measure of the acid or base property of a solution.

System: a group of related parts that move or work together to accomplish a desired result.

Tools/Materials/Equipment

- Student Companion, KSB3 for every student (online or printed)
- A shopping list of materials needed for this KSB is shown in the Preparation section of this Teacher Guide, on pages 26-28. Materials lists with images of each part appear in the Student Companion materials for KSB3.

Safety

- Students will be using a number of tools during KSB3. Be sure they are familiar with the rules and guidelines for using tools before starting this lesson. All students should wear goggles when starting to build.

Learning Activities

Engage: Divide students into six groups, assigning three of the groups to design and build an aeroponics system and the other three to design and build an ebb and flow system. (Smaller classes could have fewer groups and larger classes more groups.) Hand out KSB3 (print or online), to guide students in designing and building those systems. Tell students that there are no detailed building plans—they are to figure out what to do with the parts so as to build a system like that shown in the diagram in their Student Companion.

Explore: Students explore the materials and discuss how they should go about building the system. They do not drill any holes at this point, but they do begin to sketch their ideas for how the systems would go together.

Explain: As the student teams finish their plans, they show them to the teacher and explain how the system will function. When the teacher is satisfied he/she will give permission to get tools and begin building.

Engineer: Students construct their systems. As they drill, cut, and assemble the pieces, they continually refer to their plans, and revise as necessary.

Enrich*:* The students test their designs with water, and redesign to fix any leaks.

Evaluate: Students review each other's systems to see how they are similar and different, and how well they appear to meet the requirements of the system they are building.

Assessment

Part of the assessment for this KSB is the quality of the systems. Check to see if they are stable, functioning systems. Also check students' explanations of how the systems work in Check Your Understanding questions. Finally, discuss with the class their responses to questions about the big idea of systems.

Assessment

There are two sources of data for assessing student work in KSB3: the system that they plan, build, test, and improve; and the drawing on page 10.

The completed system. The hydroponic system should function as described in the diagram and the Student Companion. It should be free of leaks, and cycle the nutrient solution using the timer. It should also hold the lights firmly, and allow the lights to be gradually raised as the plants grow. Assign students whose systems worked to coach teams whose systems are not yet functioning.

Drawing on page 10. The drawing should be an accurate sketch of the hydroponic system, showing all of its parts, and using arrows to show how the fluid will flow.

Products

Students will complete functioning hydroponic systems that are free of leaks. They will also have completed The KSB3 Student Companion.

Answer Key for Aeroponics System

Page 3: The image to the left is not a system, while the image to the right is a system.

The image to the left is not a system because the part are not connected. The parts in the image to the right are connected and they work together to accomplish a desired result.

The goal of the aeroponics system is to grow vegetables.

Subsystems of the aeroponics system include the lights, the growing chamber, the reservoir, the pump and the timer. There are others as well.

Page 6: The sketch should show the cups widely spaced so there is room for all of the roots to be sprayed.

Page 7: Sketches of mister array should indicate that the mist will reach all of the roots. The drawing need not be to scale.

Page 8: Gray boxes represent the totes. Students' drawings should indicate a front view of the misting nozzles (on the left) and an end view (on the right.) The scheme should look reasonable before permitting the students to start cutting tubes and assembling the system.

Page 10: Check Your Understanding: The diagram should show all of the parts of the aeroponic system and how they function together. The explanation should indicated that the pump forces the nutrient solution into the tubes and out through the misters, which then spray all of the roots. The falls to the bottom of the growing chamber and then drains back into the reservoir, where it is recycled.

Page 11: Points to Ponder: Calculations need not be exact, but similar to the following:

- The inside of the tote lid is about 14" x 20" so the area of the lid is A_{Lid} = L x W = 280 in^2
- The radius of one 2" cup is 1". So the area of one 2" circle is $A_{circle} = 3.14 \times 1^2 = 3.14$ in^2
- The area of eight 2" circles is 8 x 3.14 in^2 = 25.12 in^2
- The area removed by drilling is approximately 25 in^2/ 280 in^2 = 9% so the growing chamber should stay dark enough for good growth.

Page 12: What's the Big Idea?

Name at least 8 parts of the aeroponics system: reservoire, growing chamber, pump, turbing, misters, Lights, Light timer, pump timer, nutrient solution, net cups

If one of the parts breaks down it is likely that the entire system will fail and the crops will not grow.

Responses to the next two questions will vary, but should show that the student has a good grasp of the concept of a system.

Answer Key for Ebb and Flow System

Page 3: The image to the left is not a system, while the image to the right is a system.

The image to the left is not a system because the part are not connected. The parts in the image to the right are connected and they work together to accomplish a desired result.

The goal of the aeroponics system is to grow vegetables.

Subsystems of the aeroponics system include the lights, the growing chamber, the reservoir, the pump and the timer. There are others as well.

Page 6: The challenge of designing and building a good ebb and flow system is to design the growing chamber so it drains completely. The two sketches on this page should show reasonable ideas for how this could be done.

Page 7: Sketches of the system from the front and side should show all of the tubes and their dimensions. The scheme should look reasonable before permitting the students to start cutting tubes and assembling the system.

Page 9: Check Your Understanding: The diagram should show all of the parts of the ebb and flow system and how they function together. The explanation should indicate that the pump forces the nutrient solution into growing chamber, which then floods the roots. The nutrient solution then drains back into the reservoir, where it is recycled.

Page 11: Points to Ponder: Calculations need not be exact, but similar to the following:

- Height of the Bulkhead Screen Fitting is 2”
- The growing chamber is approximately 14” x 20”.
- The volume of water at full flood = 14” x 20” x 2” = 560 in^3
- The volume in gallons is 560 in^3 x 1 gallon / 231 in^3 = 2.4 gallons
- If the nutrient solution is pumped into the growing chamber at the rate of 4 gallons per minute, it will take 4 gallons/minute /2.4 gallons, or about 1.4 minutes to reach full flood.

Page 12: What’s the Big Idea?

- Name at least 8 parts of the ebb and flow system: reservoire, growing chamber, nutrient pump, aquarium pump, turbing, air stone, Lights, Light timer, pump timer, nutrient solution, net cups
- If one of the parts breaks down it is likely that the entire system will fail and the crops will not grow.
- Responses to the next two questions will vary, but should show that the student has a good grasp of the concept of a system.

KSB4 Hydroponic Farming

Korbin Shoemaker
Harvesting lettuce from hydroponics

Overview (Days 16 through the end of the unit)

In KSB4 students mix the nutrient solution, place seedlings in their hydroponic systems, and set timers. They then monitor their hydroponic systems two or three times a week and record data, such as plant height, color, and number of leaves, as well as quality of the water and temperature and humidity of the air. Students adjust the chemistry of the nutrient solution as needed, and replace the solution completely every two or three weeks. Since monitoring the systems does not take very much time, the rest of the class period will be spent on KBS5, in which students learn CAD and the Grand Design Challenge. Finally, they graph the data and harvest the food.

Lesson Duration:

Big Idea: Feedback involves monitoring and adjusting a system to maintain a desired output.

Standards	Learning Goals
NGSS-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. STL 10. Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving. STL 12. Students will develop the abilities to use and maintain technological products and systems. EfA Themes: Design, Modelng	I can: 1. Explain how to monitor and maintain a functioning hydroponic system. 2. Make critical measurements of nutrient solution quality. 3. Adjust the chemical balance of the nutrient solution so as to maintain maximum growing conditions.

Vocabulary

Experimental variable: The variable being tested in a controlled experiment to determine its effect on the outcome. It is also called the independent variable or manipulated variable.

Control variable: Factors that may make a difference in an experiment, but which are not intentionally being studied. These variables are to be kept the same.

Outcome variable: The variable which is being measured to determine which trial is most successful. Also called the dependent variable, respondent variable, or measured variable.

Tools/Materials/Equipment

- Projector
- Computer
- You Tube Video
- Student Companion, KSB4 for every student (online or printed)
- It is likely that no additional materials will be needed, other than those used to set up the hydroponic systems in the first place.

Safety

Although only safe chemicals are involved students should wear goggles and gloves when conducting chemical tests.

Learning Activities

Engage: Explain to the students that from now on they will be both agricultural engineers and farmers, tending their crops and using scientific measurements to provide feedback to help them determine what the plants need to maintain healthy growth.

Explore: The students test their systems with plain water first to be sure they function. They then read the instructions on the nutrient solution package, mix the solution and start their systems. They also adjust lights and set timers, then place seedlings in cups and Rockwool® cubes.

Explain: The teacher introduces the process of monitoring the systems as a feedback process, such as the kinds of measurements doctors do to maintain human health, and making sure people have good nutrition and exercise.

Engineer: Maintenance is usually the work of a technician, while design is the work of an engineer. Every now and then ask the students to think about the monitoring process. How could it be improved?

Enrich: Students take measurements two or three times a week, learning how to maintain their systems, and how to troubleshoot problems. Chemical tests include pH and TDS (total dissolved solids, measured in parts per mission, or ppm).

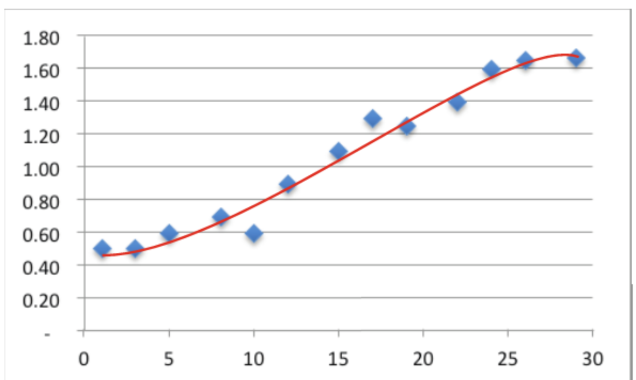
Evaluate: Each time students make measurements they should evaluate the effectiveness of their hydroponic systems. They should conclude this activity near the end of the unit by graphing their data to present to the client as part of the Grand Challenge.

Instructional Hint

Graphing and interpreting the results of the students' experiments will provide an excellent opportunity to provide experiences aligned with the following middle school Common Core State Standard in Mathematics:

> CCSS-M 1. Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.

Lead the students in a discussion about question 4 in **Check Your Understanding.** Notice that the growth pattern starts off gradually, increases, then begins to level off in a classic "S-curve" common for many types of growth. The data points that do not fall on the curve are probably due to measurement errors, since it is not likely that the planet will shrink. At this point the teams can draw a curve through the data points showing how they think the plant actually grew, ignoring errors in measurement, as shown below.



Have the students draw smooth curves through their data points and have pairs of teams work together to comment on each other's data. You may need to point out that an experiment is not a contest to see who can grow the best plant. Instead, both teams "win" by learning how to design the best hydroponic system. Students can compare their scatter plots side-by-side, or plot the data from both teams on one graph using differently colored points.

Assessment

It is important not to hang the success of the project on production of a healthy crop; although that is a good goal for the students. Success involves taking regular and accurate measurements, learning what those measurements mean, and taking action to maintain a healthy environment for the plants.

Don't wait too long to use the Teamwork Survey on page 8. It is best to have students reflect on their teamwork and improve their interpersonal skills before problems develop.

Answer Key

Page 5: Each day students take data from their hydroponic systems they complete one row of the table. They should fill in the date, the pH (acid/base) level, the measurement of Total Dissolved Solids using a TDS pen, and the depth of their nutrient solution to check on evaporation. The remaining columns are for recording plant growth. The students will need to determine how to measure plant growth before filling in these columns. Students should use a different sheet of paper if that would be easier.

Page 6: Answers will vary since students have different data. The response to question 4 should demonstration understanding of the concept of feedback.

Page 7: 1. The response to this question should illustrate the concept of control of variables. 2. This calls for personal opinions; so answers will vary.

Page 8. This teamwork assessment can provide a valuable focus for discussion, allowing students to share their feelings about the teamwork efforts so far, and to ensure that students understand how important teamwork is, both in engineering and in many different aspects of daily life.

Pages 9-10: Check Your Understanding

1. b
2. c
3. c
4. c
5. c

Page 11: Students responses should indicate understanding of the concept of feedback.

KSB5 Modeling With Computer Aided Design (CAD)

Fredesignfile.com. Creative Commons.

Overview (Days 18, 19, 20, 21, 22)

Students learn to use Computer Aided Design (CAD) software on a simple project, to develop their skills in preparation for the Grand Design Challenge later in the unit. A middle school teacher produced a series of five video tutorials to show students how to use Google SketchUp, a free software program that will work on a wide variety of computer platforms. However, other CAD software can be used instead. At the end of the lesson students create a 3D model of an apartment building, which they will later use to demonstrate their solution to the Grand Design Challenge.

Big Idea: Models are a powerful means for analyzing and predicting the behavior of systems.

Lesson Duration: 4-5 days

Standards and Learning Goals

Performance Expectations	Learning Goals
NGSS: 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. STL17 K. The use of symbols, measurements, and drawings promotes a clear communication by providing a common language to express ideas. EfA Themes: Modeling	I can: 1. Use CAD to design an apartment building with at least one wall that has no windows. 2. Create models of hydroponic equipment, or download relevant models from the SketchUp Warehouse using sufficient skill in CAD

Vocabulary

Computer Aided Design (CAD): Computer software for creating digital models.

Tools/Materials/Equipment

- Projector
- Computer with Google SketchUp (or other CAD software) loaded
- You Tube Video
- Student Companion, KSB5 for every student (printed or online)

Learning Activities

Engagement: Discuss the different 2D drawings of apples on page 2, and how the drawings might be useful for different purposes. Use this discussion to introduce 3D modeling using CAD. Show a short video about CAD and describe its advantages over drawing.

Exploration: Students use one or two of the five tutorials to learn how to use SketchUp (or another software package.

Explain: Discuss with students that there is still an important place for hand drawing, using the table on the bottom of page 3 to help them think about when CAD is better and when hand drawing is better. The students should also appreciate that a CAD model is more than a drawing that can be changed easily. It allows the user to make and test predictions, such as where shadows will fall at different times of day.

Engineer: Students continue through the rest of the video tutorials, working in pairs to check each others' understanding, using the checklists in the Student Companion.

Enrich: Students design and build a model of a large apartment building.

Evaluation: Students critique their own and the teachers' building models using a score sheet.

Assessment

The 3D model of an apartment building that the students construct should provide adequate evidence of their competence in using SketchUp. The score sheet on page 5 provides a good opportunity for students to evaluate their own skill, and to receive feedback from a classmate.

If students need additional assistance consider pairing students with greater skill with those who have less skill, until all students are able to use the essential software tools.

Answer Key

Page 2: There are no right or wrong answers. The questions are intended to provoke discussion leading to the realization that different types of drawings have different purposes.

Page 4: Answers will vary. Look for understanding of the process of making tradeoffs (more of one feature means less of another.)

Many careers require experience in using CAD, such as architect, drafters, car designers, fashion designers, electrical contractors, cabinet makers and other carpenters, and all types of engineers (mechanical, structural, manufacturing, electrical, transportation), etc.

Page 6: Points to Ponder: Cad or Hand Drawing?

The responses are a matter of judgment. However, the following responses seem reasonable:

1 CAD is much easier to use when drawing precise dimensions.

2. Definitely hand drawing.

3. CAD if manufacturing drawings are needed.

4. Drafters, architects and engineers are the first careers that pop up. Students who look a little further will find careers such as fashion designers, jewelers, illustrators and artists.

Page 7: What's the Big Idea?

There are multiple answers to these questions. The purpose of these questions is to urge students to share their ideas about CAD. Invite students to talk about their answers with another student, rather than view these questions as a test.

Grand Design Challenge

Overview (Days 23 to 35)

The students receive a letter from The Community Council asking for their help. The Grand Challenge is to create a vertical farm design using a 3D modeling program, and demonstrate an operating hydroponic system to show that they know how to grow food with hydroponics. Students use the Informed Design Process to meet the challenge.

Big Idea: Vertical farming is a bold and innovative design concept to provide healthful food in urban environments. Like all new technologies a vertical farm must:

- Meet the needs of people and the environment.
- Make best use of resources, including money, tools and materials, energy, information, time, and people.

Lesson Duration: Approximately thirteen 45-minute periods

Standards and Learning Goals

Standards	Learning Goals
NGSS-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. NGSS-MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. STL 9. Students will develop an understanding of engineering design. STL 11. Students will develop the abilities to apply the design process. STL 15. Students will develop an understanding of and be able to select and use agricultural and related biotechnologies. EfA Themes: Design, Modeling, Systems Thinking Resources, Human Values	I can: 1. Apply what I learned through the KSBs to design a vertical hydroponic farm on an external apartment wall. 2. Use the Informed Design Process. 3. Work effectively with teammates. 4. Communicate a final design idea with a CAD drawing, hydroponics display, and report.

Tools/Materals/Equipment

- Projector
- Computer with Google SketchUp (or other CAD software) loaded
- Student Companion, Grand Challenge, for every student (printed or online)

Learning Activities

Engage

Discuss the letter from The Community Council (Page 2) with the students. Help them rephrase the grand challenge in their own words. Then remind the students of the Informed Design Process (IDP) (Page3), explaining that the Student Companion will guide the students through each stage of the design process. Point out the rubric on page 15, at the end of the Student Companion, which you will use to evaluate their work.

Stage 1: Clarify Problem Specifications and Constraints. Students work individually to write their understanding of the design challenge, criteria and constraints (Page 4). They then meet as a team to see where they agree and disagree, going back to the letter if necessary to resolve disagreements. Students are free to change their written ideas and add an additional sheet if they wish.

Lead a class discussion to be sure that everyone is on the same page regarding what is required: 1) a design for a vertical farm on a building of their choice (one of the buildings designed during KSB5 will do); and 2) A completed hydroponics system and report of the data showing successful plant growth.

Explore

Stage 2: Research and investigate. Student teams review what they learned in the KSBs (Pages 5 and 6). Then they survey five of their friends (who could be in the same class) to see what kinds of fruits and vegetables they like best (Page 7) and tally the results. Research conducted to better understand the need is an important part of the IDP. The students will use this information when they plan their vertical farm.

Stage 3: Generate Alternative Designs. Students work as individuals with paper and pencil to come up with different ideas for a vertical farm (Page 8). Then the students develop a CAD model of their best idea. If there are enough computers each student should create their own model; but if computers are in short supply they can work in teams of two.

Explain

Stage 4: Choose and Justify the Optimal Solution Teams use a Decision Matrix (Page 9) to evaluate different design ideas proposed by the team members. The teams construct a decision matrix, in which criteria and constraints are listed in the first column, and different models produced by the team members are listed at the head of subsequent columns. The teams work together to rate each idea against each criteria and constraint, awarding it a score from 0 (does not meet a criterion) to 5 (meets criterion very well.) If an idea does not meet a constraint, it is not considered further.

Engineer

Stage 5: Develop a Prototype (Day 27). Student teams develop a detailed plan for the vertical farm, considering tradeoffs. They create drawings and a 3D model, and prepare their hydroponic system for demonstration.

Stage 6: Peer Review (Estimate Days 28) Students teams present their ideas to their classmates who act in the role of consulting engineers to provide critical feedback.

Enrich

Stage 7: Redesign the Solution (Day 29) Teams revise their vertical farm designs based on feedback from the other teams.

Evaluate

Stage 8: Communicate Your Achievements (Day 30) Teams make presentations to their clients from the apartment complex (classmates acting as the client), about their final design. Presentations illustrate the entire trajectory of development, including designs that were not selected and why, feedback on the final design, and modifications. Presentations to show how the design finally achieved meets the criteria and constraints of the problem. The class evaluates each project regarding how well it meets the needs of the client.

Products

There are three products from this set of activities: 1) the students' completed Grand Challenge Student Companion; 2) the vertical farm design developed by each group; and 3) The student's completed hydroponics system and data display.

Assessment

Use the rubric on pages 4 and 5 of the Student Companion to assess the students' vertical farm design. Use the "Final Project Assessment" on page 24 to rate the students on how well they and their team did on each stage. The students should rate themselves first, then the teacher should rate the students.

Use students' responses to questions throughout the Grand Challenge as further information on the work of individual students.

Answer Key

Page 6: Show a design for a vertical farm, and demonstrate a hydroponic system that is growing vegetables.

Criteria are that the vertical farm design should

- Take advantage of as much sunlight as possible.
- Provide maximum space to grow fruits and vegetables year round.

- Include a plan for planting and harvesting.
- Make our building more attractive.

The constraint is that it be ready to show in one week. (The teacher can adjust this time based on actual constraints of the school schedule.)

Pages 7 and 8: Students summarize what they learned in their own words what they learned in each KSB, and how it will help them meet the current challenge.

Page 9: Students should have family and/or friends check the items that they commonly eat. Use tally marks to identify the numbers in the right column.

Pages 11-12: The students should show sketches of two possible ideas for a vertical farm, with labels. At least some of the ideas from page 10 should be shown in the drawings.

Page 13: All of the student on the team should record the results of the design matrix. Criteria and constraints should be filled in, and each idea should receive points for each criterion and constraint.

Page 14: All students in the team should have a similar drawing on this page for the vertical farm. Features should be labeled.

Pages 15-15: All students on the team should have similar information in the table, giving details of their team's plan. Tradeoffs considered by the team should be included at the bottom of page 16.

Page 19: Students should use the table on page 19 to critique the other teams, and to note comments on their own team's ideas. All boxes should be filled in with a "yes" if the design answered the question, and a "no" if it did not.

Page 20: This page should have notes about what the other teams said about their design. Ideas should be listed under what the other teams liked, what suggestions they offered for improvement, and additional ideas that the students' own team came up with. The page should conclude with notes about what changes would be made and which would not.

Page 22: Responses on this page will vary. It asks students about their personal reflections on the entire design experience.

KSB 1

***Name*______________________ *Date*______**

Welcome to Fresh Food Engineers

Big Idea: Sustaining the supply of food is a great engineering challenge, especially as the world's population grows.

Hydroponics System
Cary Sneider

Vertical Farms with Crops Growing on Walls
Cary Sneider

Our new company, Fresh Food Engineers, helps people who live in cities grow their own fresh organic fruits and vegetables. Today we help people construct small hydroponic systems for their apartments. Tomorrow you will help us design and build ***vertical farms*** that will cover the walls of buildings with rich crops.

As our newest engineer, your first task is to build your knowledge and skills as an ***Agricultural Engineer***—a person who develops new and improved technologies for growing and processing food. In this KSB you will learn how to grow food without soil, and find out why we think hydroponics is the wave of the future. When you finish this KSB you will be able to answer the following questions:

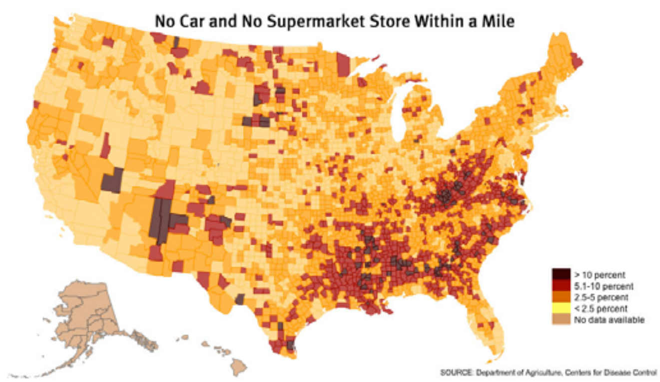
- ✓ What is a "food desert?"
- ✓ Why is the world's supply of fresh, nutritious food at risk?
- ✓ What is hydroponics?
- ✓ How do hydroponic systems function?
- ✓ How could hydroponics help provide fresh food for people in cities?

Food Deserts in the United States


U.S. department of Agriculture. Public domain

As a new employee of Fresh Food Engineers, it is important that you understand some of the problems that our company hopes to solve. Perhaps the most important of these is known as “food deserts.”

A ***food desert*** is a low-income community that is located more than one mile from a source of fresh fruits and vegetables and other healthful foods. Few people who live in these communities have cars, so they are forced to buy food from quickie markets that provide mostly packed foods with long shelf life but fewer nutrients.



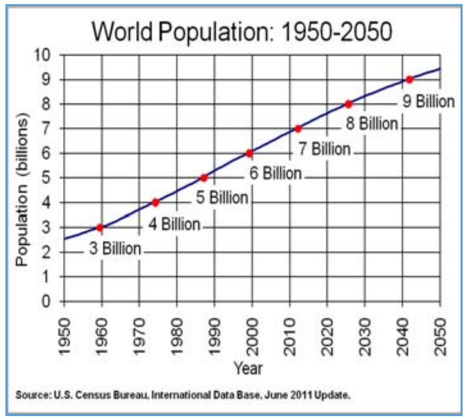
On the Internet, use a search engine to find the **Food Access Research Atlas.** This interactive map has been created by the U.S. Department of Agriculture to identify areas where people do not have access to fresh foods available in supermarkets. Use the search tool on this website and search for the city or town where you live. Summarize what you find about food access in your town.

According to the U. S. Department of Agriculture, 23 million people in the United States live in food deserts. The map above shows where these food deserts are located.

Although the problem of food deserts could be solved by building more markets where people can buy fresh food, a more difficult problem looms in the future—being able to produce enough food to feed everyone. Two problems are already becoming evident: having enough land for farms and enough water to grow crops.

Why is the world's supply of fresh, nutritious food at risk?

An even greater problem than food deserts in a local community is having enough food to feed a growing world population. According to the United Nations, today's world population of more than 7 billion people is expected to increase to 8 billion in 2025 and more than 9 billion by 2050.[1]



In addition to the problem of having more people to feed, the growing population creates two very difficult problems for agricultural engineers to solve:

1) Less land for growing food. As the population grows, more people choose to live in cities. As cities grow developers turn farmland into houses, apartments, and businesses. So the amount of land that can be farmed—called ***arable*** land—has been shrinking.

Cary Sneider

Bigger cities means less land for farms

2) Less fresh water for growing crops. The burning of coal, oil, and natural gas for electricity may contribute to changes in the climate, so that more areas now receive less rain than before. In order to grow their crops, farmers have diverted water from rivers to fields, creating competition between farms and cities for water. [2]

NOAA, Public Domain

More people means less fresh water

In your opinion, what could be done to solve the problem of a growing need for food, despite diminishing supply of both farming land and clean water?

[1] *UN, 2012. World Population Prospects: The 2012 Revision.* New York: The United Nations. Retrieved from: http://esa.un.org/wpp/

[2] FAO. 2011. The state of the world's land and water resources for food and agriculture (SOLAW) - Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London. Retrieved from http://www.fao.org/nr/solaw/main-messages/en/.

Think Like an Engineer

As shown on the previous pages, the need to provide sufficient fresh food for people in cities is a serious problem, especially as the human population continues to grow. A very exciting idea that may help solve this problem is **vertical farming**—using the vertical space on tall buildings to grow food.

The vertical farm in this image is an entire building in which food is grown on the interior of every floor. The leaders of the Fresh Food Engineers company think that vertical tower farms are too expensive, since land in cities costs a lot, and building such structures may cost millions. Instead, our company is interested in farms that will grow crops on the sides of existing buildings.

Cjacobs627 at English Wikipedia

Your challenge will be to design a vertical farm on the side of an apartment building. First, however, you will need to learn how to grow food with ***hydroponics***—that is, without soil and by recycling the water over and over. You will also need to learn **Computer-Aided Design**, or CAD, which was used to create the image at right.

First, here are two ideas to help you think like an engineer:

1. Vertical farming is an excellent example of sustainable development and is one way to meet the needs of today without sacrificing the ability to meet the needs of future generations. What are three other example of sustainable development?

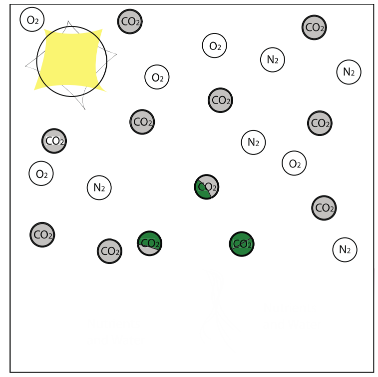
1.

2.

3.

What Do Plants Need?

Whatever growing method is used, agricultural engineers must be able to answer the question: What do plants need to grow? Look at the diagram and list three things it shows that plants need to grow.



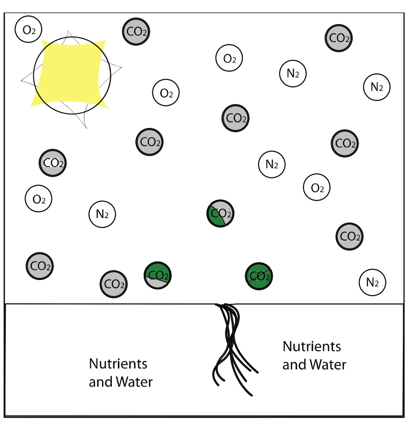
1__________________________________

2__________________________________

3__________________________________

It may be hard to believe, but the raw material that plants use to build their stems, flowers, roots and leaves does not come from the soil. Plants take in carbon dioxide (CO_2) from the air and water from the ground to create carbohydrates and to release oxygen back to the air. This process is unique to plants, as only they can use the sun energy to split water molecules.

Cary Sneider



The vast majority of our fruits and vegetables come from farms like the one shown above. But soil farming is not the only way to grow food. The diagram on the left shows a plant growing without any soil—just water. What else does it need besides water to grow?

1__________________________________

2__________________________________

What Is Hydroponics?

The Greek word ***hydro*** means water; and ***ponos*** means labor or work. Hydroponics is a method of growing plants in water without soil. The water must be enriched with a few minerals and the plants need some support for their root system.

There are many different hydroponic methods. The image below shows a hydroponic farm in which the plants are watered through a plastic trough under each row of lettuce.

Ryan Somma, Creative Commons

Leafy Green Vegetables in a Hydroponics Farm

Hydroponics is becoming more and more common in countries like Singapore, where there is very little arable land to grow crops.

Why do you think hydroponic farming is becoming more common around the world?

____

____

Watch the following video to see how hydroponics is being used in our world today.

[VIDEO LINK INSERT http://opb.pbslearningmedia.org/resource/agd14.pd.steam.green/greenhouse-labs-in-schools/]

Advantages and Disadvantages of Hydroponics

Without additional arable land it is difficult to grow enough food for our growing population. There are many solutions to this problem, including new kinds of crops and fertilizers, and genetically modifying crops that grow faster or produce more edible food. But some agricultural engineers suggest that we find a solution that doesn't rely on soil at all—hydroponics. In order to be a good hydroponics engineer you need to understand the pros and cons. Here is what some professionals have to say.[3]

Pros

- No soil is needed.
- Fewer pesticides and herbicides are needed.
- Less water is required. No water is wasted because it is recycled.
- Plants grow faster and have bigger yields.
- Some hydroponically produced plants are more nutritious and taste better.
- Gardeners have more control over the nutrient amounts their plants receive.
- Less space is needed. Plants can be closer together than they could in soil. This is because the roots can be close together and event tangled up since they are constantly bathed in nutrients. In soil the plants have to be spaced farther apart so the roots have room to spread out and find nutrients in the soil.

Cons

- Some plants cannot be practically grown using hydroponics, like melons and squash because they take up too much space.
- Hydroponics requires a lot of technical knowledge.
- Hydroponic equipment can be very expensive.
- Crops must be maintained more frequently.
- If the watering system fails, plants will dry out and die rapidly.
- Given the cost of equipment, a farmer may make less money than using soil.
- Some methods require a soil replacement to hold the roots in place.

[3] http://www.guide2hydroponics.com/about-hydroponics/pros-and-cons.aspx

Deciding Between Soil Farming and Hydroponics

Ildar Sagdejev, Creative Commons

Hydroponics Farming

Artaxerxes, Creative Commons

Soil Farming

Although our company specializes in hydroponics, if it is better for our clients to use soil farming, we have a moral obligation to give them that advice. Here are some questions from clients. In each case, what do you recommend?

1. "I just purchased 15 acres of land in Oregon. It rains a lot there. Should I plan to use hydroponics or soil farming?" (Explain your answer.)

____

____

2. "I live in a large apartment building in New York City. I would like to grow my own food. Should I plan to use hydroponics or soil farming?" (Explain your answer.)

____

____

3. "I teach in a middle school in a small town. I would like my technology students to develop some skills in growing food. I have no idea if they will move to the city or country after graduation. Should I plan to use hydroponics or soil farming?" (Explain your answer.)

____

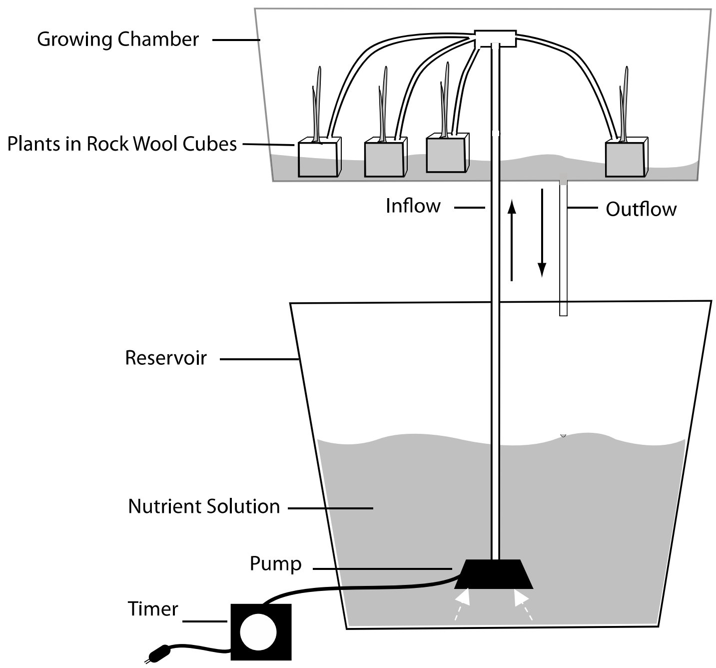
____

How do Hydroponic Systems Function?

We will investigate four types of hydroponic systems: Drip, Ebb and Flow, Nutrient Flow, and Aeroponic.

The Drip System

In the Drip System plants are placed into Rockwool® cubes, which hold moisture very well. If there is an interruption in pumping, the plants will survive for a few hours on their own.



1. Which part pushes the nutrient solution out of the reservoir?_______________

2. Which tube carries the nutrient solution up to the growing chamber?___________

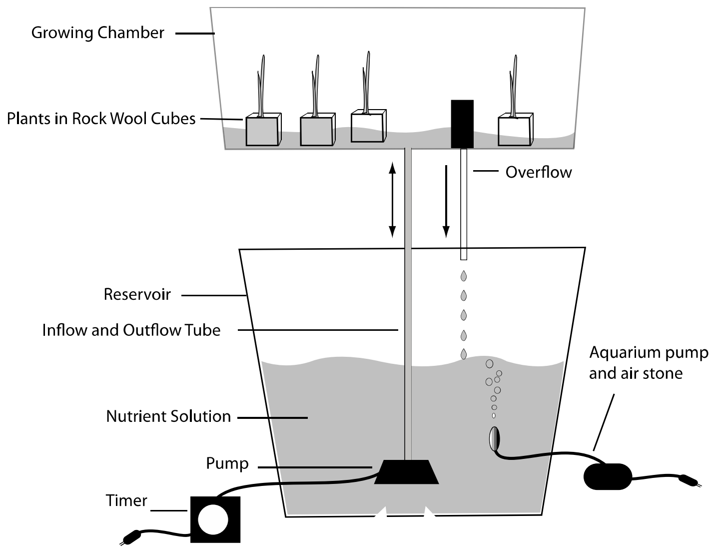
3. Which tube returns the nutrient solution to the reservoir?___________

4. How are the plants held so they don't fall over? ______________________________

5. Use a search engine to search for "Hydroponic Drip System" on the Internet to see what these systems look like. Try to find the various parts shown above.

The Ebb and Flow System

The Ebb and Flow system pumps nutrient solution up a tube to the growing chamber to saturate the plant's roots and the cubes that hold them. Then the pump stops and allows the nutrient solution to flow slowly down the same tube and back into the reservoir.



1. How does the nutrient solution flow back into the reservoir? ____________________

2. What do you think the Overflow is for? ______________________________________

3. What role do you think the timer plays? ____________________________________

4. Look up "Hydroponic Ebb and Flow System" on the Internet to see what these systems look like. Try to find the various parts shown above.

5. What is the main difference between the "Drip" and the "Ebb and Flow" systems?

____

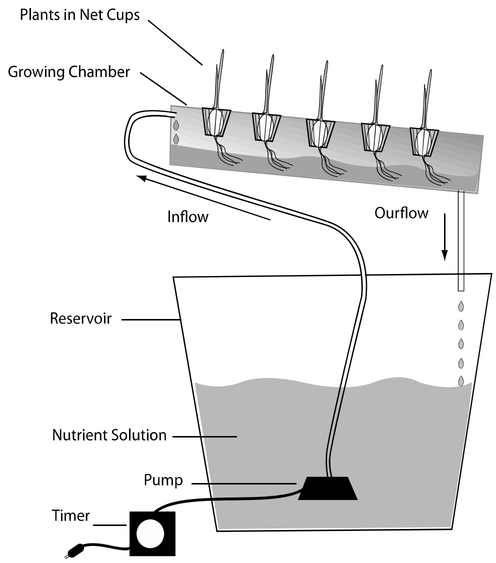
Points to Ponder

Rockwool® is made from Basalt rock and Chalk. These natural materials are melted at 1600° C and blown into a large spinning chamber, which pulls the hot gooey rock into fibers like "cotton candy." The fibers are compressed into a mat, which is then cut into slabs and cubes. (More information is available at http://www.hydroponics.net/learn/rockwool.asp)


D-Kuru

The Nutrient Flow System

In the Nutrient Flow System, the roots grow on the bottom of the growing chamber while nutrient solution is pumped into one end of the chamber and flows out of the other end of the chamber. Nutrient flow can only be used after the plants have grown roots that are long enough to reach the nutrient solution.



1. How is the Nutrient Flow System similar to the Ebb and Flow System?

____

2. How is it different from the Ebb and Flow System?

____

3. Use a search engine to search for “Hydroponic Nutrient Flow System” on the Internet to see what these systems look like. Try to find the various parts shown above.

Points to Ponder

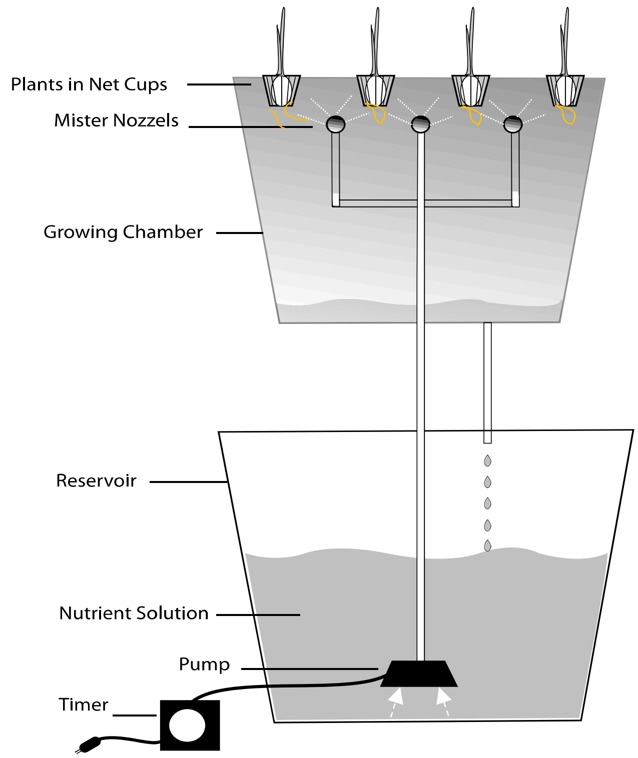
Net cups are plastic containers made especially for hydroponics. Holes in the plastic permit the roots to grow and spread out. Net cups are used in a number of hydroponic systems because they allow the roots to come into direct contact with the nutrient solution.

Net Cups

Ildar Sagdejev

The Aeroponic System

The Aeroponic System is quite different from the others, all of which bathe the roots in liquid. In this system the plants' roots are bathed in a fine mist.



1.Why do you think it is important for the pump in this system to be stronger and provide more pressure than the previous systems?

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2. The mister nozzles help to provide not just nutrient solution, but also air. Why might this improve plant growth?

---

3. Use a search engine to search for “Hydroponic Aeroponic System” on the Internet to see what these systems look like. Try to find the various parts shown above.

4. Why might an ebb and flow system need an “air stone” and an aeroponics system not need it? What function does the “air stone” serve?

Check Your Understanding

As a means of checking on your progress, do the best you can to answer the following questions.

1. What is a “food desert?”
   a. A community where there is no fresh food within 100 miles.
   b. A community more than 1 mile from a source of fresh food.
   c. A community that does not raise its own food.
   d. A l community where people cannot afford hydroponic farms.

2. Why might producing enough food be a major problem in future decades?
   a. The world population is growing rapidly.
   b. There will be less land suitable for farming.
   c. There will be less fresh water.
   d. All of the above.

3. What is sustainable development?
   a. Sustaining the growth of plants over an extended period of time.
   b. Providing sufficient funding for a project so that it can continue to completion.
   c. Meeting the needs of today without sacrificing the ability to meet the needs of future generations.
   d. Ensuring that development will continue to go on, despite setbacks.

4. Which of the following is not essential for plants to grow?
   a. light
   b. air
   c. soil
   d. water

5. Most plants in farms and gardens are grown in soil. **Hydroponics** is a way of growing plants without soil. Which of the following statements about hydroponics is NOT correct?

   a. Hydroponics uses less fresh water than soil farming.

   b. Plants grown with hydroponics require only pure water and light.

   c. Weeds do not grow in indoor hydroponic systems.

   d. Hydroponics requires less space to grow the same amount of food.

6. In which location would soil farming be a more economical choice than hydroponics?

   a. A 15-acre farm where it rains often

   b. A research center in Antarctica

   c. A space station orbiting Earth

   d. An apartment in the city

7. A hydroponic system that sprays plant roots from below is called:

   a. Ebb and Flow

   b. Nutrient Film

   c. Aeroponics

   d. Drip

8. A hydroponic system that periodically floods and drains plant roots is called:

   a. Ebb and Flow

   b. Nutrient Film

   c. Aeroponics

   d. Drip

9. How could hydroponics help provide fresh food for people in cities?

What's the Big Idea?

It is important to fully understand the following BIG IDEAS about engineering from this first KSB. Reflect on each one and explain what it means to you. There are no right or wrong answers—it's your understanding that counts.

Supplying enough food for all people is a great engineering challenge especially as the world's population grows.
Sustainable development is a way to meet the needs of the present without sacrificing the ability to meet the needs of future generations.

Name________________________ **Date**______

KSB
2

Design and Build a Platform

Big Idea: The Informed Design process uses knowledge and skills to solve problems rather than just guessing or trial-and-error work.

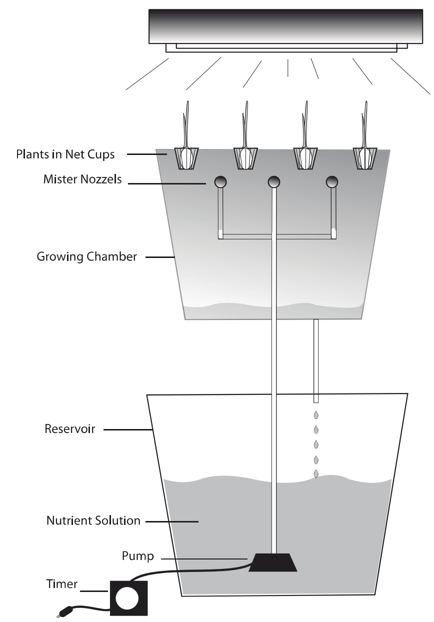
Image Courtesy of Cary Sneider

Now that you know what our company is all about, it’s time to start designing and building hydroponic systems. First you will need to design a stable and easily adjustable platform to hold the growing chamber and reservoir. In order to do that you will need to use the Informed Design Process. When you finish this KSB you will be able to answer the following questions:

- ✓ What is the Informed Design Process?
- ✓ How does the informed designing differ from trial-and-error designing?
- ✓ How can making a tradeoff help improve a design?
- ✓ What is a design matrix used for?
- ✓ What are some useful tools for building structures?

Step 1. Why Do We Need a Platform?

Recall the four hydroponic systems from KSB1. Each system has three components: a reservoir that holds the nutrient solution, a growing chamber, and a pump with timer to deliver nutrient solution to the plants.



Your first task is to design a structure that will hold both parts of the system, and that will hold lights suspended above the plants. The lights will need to be raised as the plants grow higher.

Your teacher will give you a list of the materials that can be used to build the platform and lighting support, and the cost of the materials. Your job is to design the optimal support system at the lowest cost.

Design Criteria (features of a successful design solution) are as follows:

- The structure must be stable and strong enough to support the system
- It has to allow access to all parts of the system
- There must be an open space where tubes can run between the two parts
- The structure can hold lights.
- The cost should be as low as possible, provided the above design criteria are met

Constraints (limits) of the problem will consist of the materials and tools available and the time in which the project must be completed. You teacher will provide this information. Write it down here.

What materials can I use?

____

____

____

____

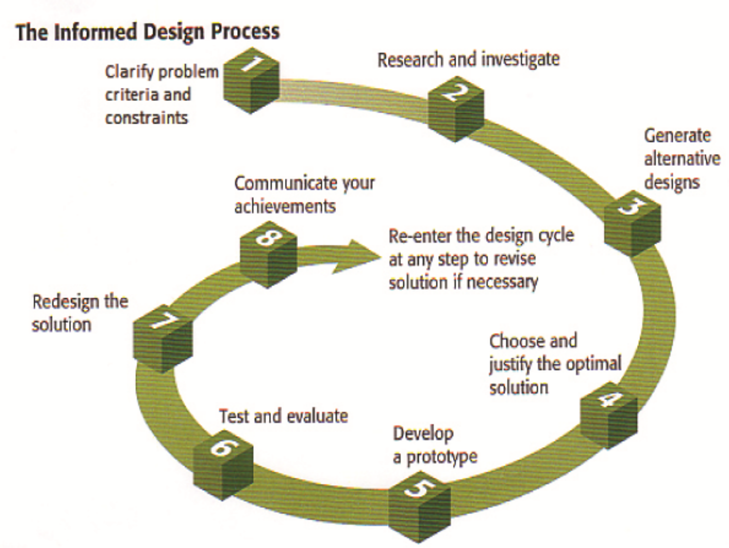
By when must it be completed?

____

The Informed Design Process

The Informed Design Process is a means for finding the optimal solution to a problem, given constraints. It consists of eight steps in a logical sequence that do not have to be followed precisely.

Notice that you have already done Step 1, Clarify the problem using criteria and constraints. You will need to return to that page frequently, such as when you compare different solutions to see which best solves the problem. So, go on to step 2.



Step 2 Research and Investigate

Your teacher will provide you with the reservoir and growing chamber for the hydroponic system you will build. You will need to conduct research like you did with the tallest tower to figure out how to design your structure. First, think about what you know about the shapes that make structures strong. Then, measure these to determine how large a structure will be needed. Finally, look back at the system diagrams from KSB1 to determine where tubes will need to go between the growing chamber and reservoir. Summarize your findings here.

Step 3. Create Alternative Designs

Work as a team to come up with several different ideas for a structure and lighting support. Then, each student should work independently to sketch one of the designs. Label the different parts to indicate the materials they are made from (for example, 2” x 4” lumber, plywood, etc.)

Try it out! Build a prototype of your design using straws and paperclips to test its strength and stability.	
What are the advantages of this design?	What are the disadvantages of this design?

Think Like an Engineer

Making Tradeoffs

It is rare that a solution meets every criterion. A **tradeoff** is a choice that gives you more of one criterion and less of another. For example, consider the tradeoff between a food that tastes better, but has less nutritional value; or between studying for an exam versus spending more time with friends, or buying cheaper colored pencils that are not as strong or vibrant.

Think about how you might modify your design to make the best tradeoff between strength and cost. What will you do?

Calculate the Cost of Your Preferred Design

Your teacher will give you a list of costs for each of the materials you can use to build the platform. **Calculate the cost of your design** by listing each part, and adding up the cost of all the parts.

Bill of Materials

Part	Item Cost	Quantity Needed	Total Cost
Total			

Step 4 Choose and Justify the Best Solution

A design matrix[1] is a table with columns and rows that help you make good decisions. The criteria and constraints for the problem are listed in the left column. The choices are listed along the top. Assign letters A, B, C,D to the designs from different team members.

Award 0 to 5 points for each idea on each criterion. The purpose is to consider the designs, not who made them. Try to judge your own idea as fairly ad the others. Discuss how well each of the designs meets the criteria and constraints.

0 = does not meet **3 = mostly meets** **5 = Meets very well**

Criteria	**Design A**	**Design B**	**Design C**	**Design D**
	Cost:	**Cost:**	**Cost:**	**Cost:**
Can support both parts of the system				
Provides easy access				
Open space for tubes between the parts				
Can adjust height of the lights				
Total Points				
Constraints (Yes-No)				
Requires only available materials				
Can be built in the time allotted				
Costs no more than approved budget				

4. The team should decide which design best meets the criteria and constraints and offers the best **tradeoff** of strength versus cost.

5. Which did your group decide? __________ What tradeoffs did you make?

[1] A decision matrix is also called a Pugh Chart, named for Stuart Pugh, who was a professor at the University of Strathclyde in Glasgow, Scotland.

Step 5. Develop a Prototype

Present your chosen design to the teacher. In order for your teacher to approve the design and give you permission to start building you will need to do the following:

1. If you made a straw model of your platform design show it to your teacher and ask for suggestions on how to improve it.
2. Show your teacher a completed decision matrix to justify your choice, showing how your design will meet the criteria and constraints of the problem.
3. Calculate how much it will cost and estimate the time it will take to build it.
4. Request the tools and materials that you will need.
5. Work as a team to build the platform, following the design.

Safety is of great importance in every classroom, but especially where tools are involved. Your teacher will provide safety guidelines for using the specific tools, equipment, and working spaces in your classroom.

Step 6. Test and Evaluate

In the next KSB you will put your platform to the test by using it to support the reservoir and growing tray, and to connect the various hoses and power cords. When you run into difficulties—which happens with nearly all new designs—take notes on what happens and how it might be fixed.

Step 7. Redesign the Solution

Designs are almost never perfect. If you encounter difficulties with the platform as you build it, talk with your teacher about how to modify it to improve stability, access, or solve other problems.

Step 8. Communicate Your Achievements

Be prepared to describe your design, explain why you chose it, and what you might do differently if you had to do it again, with the other engineering teams in your class.

Check Your Understanding

Decisions can be difficult. But they are much easier if you use a design matrix, even for everyday decisions. For example:

A high school engineering student saved up $100 to have a pizza party with nine of her best friends, but she couldn't decide where to go. So she created a design matrix (also called a Pugh Chart) as shown below.

She decided to go with Best Pizza.

0 = does not meet   **3 = mostly meets**   **5 = Meets very well**

Criteria	Best Pizza	Luigi's Pizza	Big Pie
Tastes Great	5	3	2
Nearby	2	1	1
Seating for 10	4	3	5
Total Points	11	7	8
Constraints (Yes-No)			
Cost less than $100	No	Yes	Yes

1. Based on the design matrix, do you agree with her choice?
    a. Yes because Best Pizza has the most points.
    b. Yes because Best Pizza tastes great and it's nearby.
    c. No because Best Pizza does not meet the constraint of the problem.
    d. No because she just likes to go to Best Pizza.

2. Which of the following represents a ***tradeoff***?
    a. Deciding to go to Big Pie because you get good seating and pretty good pizza.
    b. Deciding to go to Big Pie because you give up tasty pizza for good seating.
    c. Deciding to go to Big Pie even though it will cost a little more.
    d. Deciding to go to Big Pie because it has better scores than Luigi's.

3. Why is it usually necessary to make tradeoffs when designing a product?

4. Creating a design matrix takes time and effort. In your opinion, why do engineers use it when they have an important decision to make?

Questions 5 and 6 are about the 8-step **Informed Design Process.**

5. Imagine you overheard someone say that the Informed Design Process is a way of trying a bunch of different ideas until you find something that solves the problem. Would you agree with that? ___________ Explain why you agree or disagree.

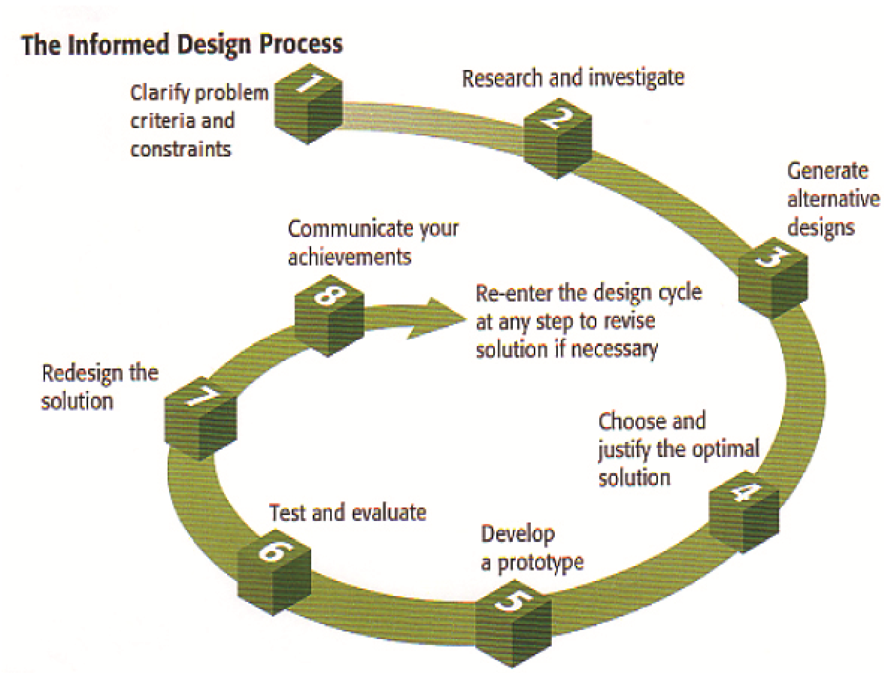
6. How would you describe the Informed Design Process?

7. Did you use any tools to build your platform? __________ If yes, what were they? and what experience have you had with these tools before?

What's the Big Idea?

The most important BIG IDEA in this KSB is the Informed Design Process, in which you use knowledge and skills to solve problems by researchin the challenge, brainstorming ideas, and making decisions, rather than just trial-and-error.

Like any new way of doing things it may take some time to get used to. Share your thoughts about The Informed Design Process by answering the questions below.



What did you LIKE about applying the Informed Design Process?

What did you DISLIKE about applying the Informed Design Process?

Name______________________ Date______

Engineer an Aeroponics System

Big Idea: Systems have parts that work together to achieve desired results.

Image Courtesy of Cary Sneider

Image Courtesy of Cary Sneider

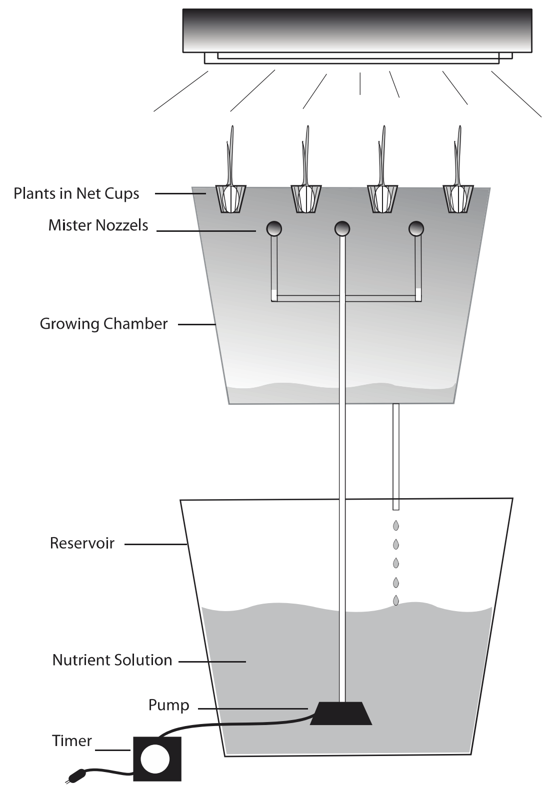
Like cars, airplanes and houses, hydroponic systems are made of many parts that do very little on their own, but accomplish something quite remarkable when assembled and properly maintained. They can be used to grow food! The system that you have been assigned to build works by spraying the roots of plants with a ***nutrient solution***—water with dissolved minerals that plants need to survive.

When you finish this KSB you will be able to answer the following questions:

- ✓ What is a system?
- ✓ How does an aeroponics system function?
- ✓ What are the inputs, outputs, and goals of an aeroponics system?

A. Introducing the Aeroponic System

Hydroponics is a way to grow food that uses less land and much less fresh water than soil farming. As a member of our engineering department at Fresh Food Engineers you will learn to design, build, and maintain an aeroponic system.



In the aeroponic system the roots hang in the air and are misted with water that includes a solution of nutrients. The mist is created by a series of small nozzles. These are supplied with nutrient solution that is pumped from the reservoir.

The pump is submerged in the nutrient solution. It is controlled by a timer so that it turns on and off every few minutes. If the roots are sprayed constantly they will rot. If they are allowed to dry out the plant will die.

Your team will design and build an aeroponic system that will:

a) Support the plants so they do not fall over.
b) Provide the nutrients that the plant needs for growth.
c) Have no leaks.
d) Use the materials that are provided, as shown on the next page.

Work together as a team to make decisions and accomplish these tasks. But everyone on the team must create their own drawings and answer all questions.

Points to Ponder: What Is a System?

The idea of a system is very important in engineering. You can't design, build, or fix anything at all complex without understanding it as a system.

A *system* is a group of related parts that move or work together to accomplish a desired result.

Cary Sneider

Stephen Haner

Is the image **above** a system? Yes___ No___

Is the image at **right** a system? Yes___ No___

How do you know?

____

____

Systems have goals (the desired result), resources (such as the materials that go into the system and the energy sources used), processes (events that go on inside the system) and outputs (the actual result). For hydroponic systems, the goal is to grow plants, and the resources include light, air, and nutrients.

What is the goal of the aeroponics system on the previous page?

____

Systems also have subsystems, which are smaller systems made from related parts. The goals of subsystems contribute to the goal of the larger system.

What are two of the main subsystems of the aeroponics system?

The ___________________________ and the ____________________________

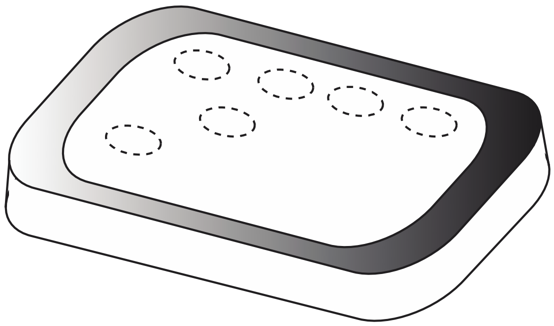
B. Tools and Supplies

- Check to see if you have all of these supplies. (Tools are not shown in this list.)
- Put a checkmark next to the name of each item as you identify it.
- If you are missing anything ask your teacher about it.

Item	Quantity	Size	Item Description	Image
Growing Tray	1	10 gallon	10 Gallon Tote (or equivalent)	
Reservoir	1	18 gallon	18 Gallon Tote (or equivalent)	
Power strip	1	115V 6 outlet	6 Outlet Power Strip (or equivalent)	
Aquarium Pump	1	115V 250 g/h	Active Aqua 250 Gallons Per Hour	
1/2" Black Tubing	1	1/2"x 25 ft	1/2" Inside Diameter Black Tubing	
1/2" Stopper	2	1/2"	1/2" Stopper	
1/2" Bulkhead Barbed Fitting	1	1/2"	1/2" Bulkhead Barbed Fitting	
1/2" Barbed Elbow	2	1/2"	1/2" Barbed Elbow	

1/2" Barbed Tee	2	1/2"	1/2" Barbed Tee	
1/2" Barbed Shut-off valve	1	1/2"	1/2" Barbed Shut-off valve	
Rubber Gromet	1	0.625”	Use to avoid leaks at the bottom of the growing chamber	
Misting Nozzles	8	SMALL	EZ Clone 360 Vertical Spray Misting Nozzles	
Net Cups	8	2"	2" Net Cups	
Sheet Plexiglas	1 (share)	16” x 24”	To test aeroponics spray pattern	
LED or Fluorescent Growlight	1	115V 45 W LED or 75W CFL	LED Growlight or T5 Grow Light 2 or 4 bulbs, 2 ft. long 6500k	
Analog Timer	1	115V	24hr grounded timer for light	
Analog Timer	1	115V	15 minute grounded timer for pump	
Marking Pen	1		Permanent marker to mark location of holes to be drilled	

C. Step 1 Plan Location of Holes for Net Cups



The lid of the 10-gallon tote serves as the plant carrier in this hydroponic system, since it holds the eight net cups that support the growing plants. The plants need to be located as far away from each other and from the sides of the tote as possible, so the roots have the maximum space to be watered by the mister nozzles.

1. Measure the length and width of the part of the lid that will be inside the growing cell. Also measure the maximum diameter of the net cups.

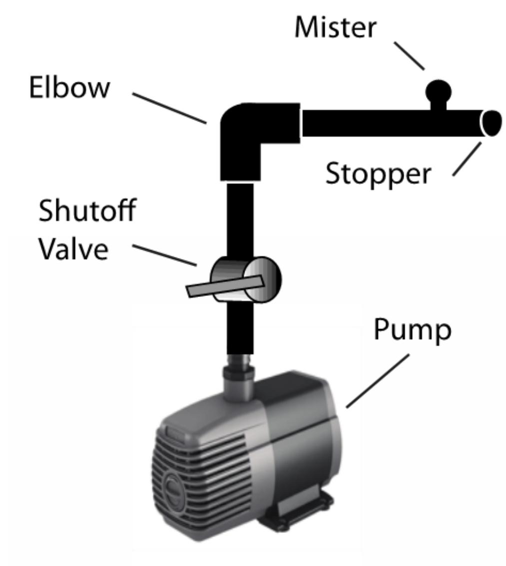
2. Research the maximum width of the mature plant you are planning to grow. Then, draw a sketch of the lid below, and indicate on the sketch how far the eight cups should be from each other and from the sides of the lid so they will be spaced as widely as possible.

3. Use a measuring tape or ruler and marking pen to locate the center of each hole on the lid.

4. Show your work to your teacher, in order to receive approval to drill the holes with a 2” hole cutter.

D. Step 2 Design the System

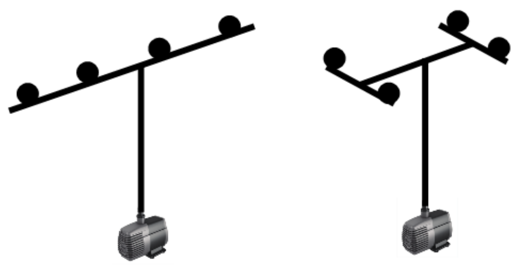
The roots of the plants receive their food through a fine mist spray. Your team has eight misting nozzles in the kit of parts.



Although you do not have to use all eight, the nozzles that are used must be arranged inside the reservoir tub so that ALL plants receive a spray of nutrient from the nozzles.

The illustration at the right shows how to connect the pump to a shut-off valve and a mister nozzle.

Your job is to design an arrangement of tubes, ½" elbows, Ttee joints, and mister nozzles so that all of the plants will be sprayed equally. Two possible arrangements are shown at right.



In the boxes below, sketch your design for the design mister array, showing a top view and side view. Write the length of each tube on both sketches.

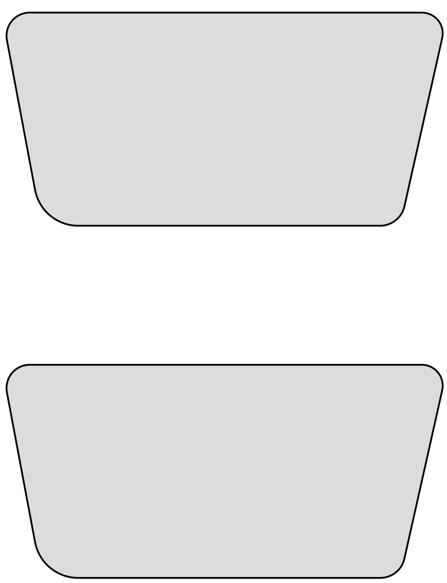
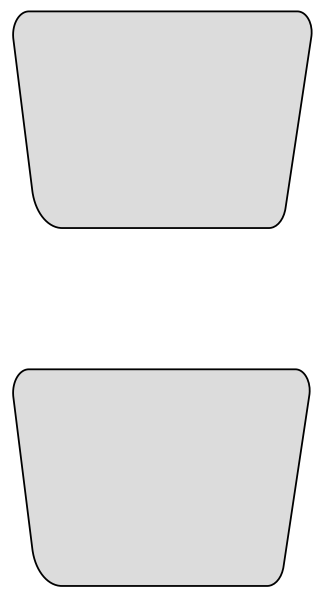
Top View of Mister Array	Side View of Mister Array

Look at the diagram of the hydroponic system on page 2. Notice how the two parts of the system are connected.

On a separate sheet of paper, sketch the side view and front view showing the tubes that run between and inside the two parts of your hydroponic system. When you are satisfied with your design, draw the tubes on each of the two diagrams below

On the diagrams, show the dimension, in inches, for the length of each tube. Add a certain amount to the length to allow for the tee fittings.

Show where you will insert a shutoff valve to adjust the flow. If the shutoff valve is between the reservoir and growing chamber it will be easy to adjust the flow.

Side View of Aeroponic System	End View of Aeroponic System
	

A hole in the bottom of the growing chamber for the drain will need a bulkhead barbed fitting in a rubber grommet, so the tub does not leak. Show these in your drawings.

You will also need a hole in the side of the reservoir for the power cord. Show where it will be located.

When you are finished, show the teacher your sketches. When your teacher approves your design, you can start building.

E. Step 3 Build and Test the Mister Array

Safety Note: Before you start building, be sure you are familiar with all of the safety rules your teacher has provide for the use of tools.

Measure and cut the lengths of the ½" inside diameter tubing you will need, and assemble the mister array. If you have difficulty slipping a tube over the outlet of the pump, use the hot glue gun nozzle to gently warm the end of the tubing to make it soft. **Safety Note**: **Do not touch the nozzle of the glue gun or the heated end of the tubing**!

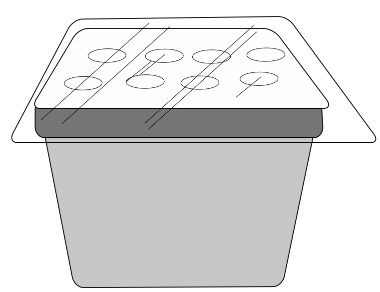
When drilling holes in the ½" tubing for the nozzles, place the tube in a vise and use a portable drill with a 1/16" twist drill to make a hole for each nozzle. Insert a stopper into the end of the tube.

To determine the twist drill size that you will need to drill the two holes at the bottom of the growing chamber, measure the diameter of the threaded section of the bulkhead barbed fitting (the part that passes through the bottom of the growing tray and connects to the tubes.) Record that diameter here: ______

Find the hole saw (or step drill) that is same size as the above dimension or very slightly larger.

Assemble the entire system. Then pour about three to four gallons of water into the reservoir and test it as shown below. Check to see if there are any leaks. If there are, pour the water out, and re-seal the fittings using silicon caulk or hot glue gun.

Test the mister array by removing the lid from the growing chamber and replacing it with a sheet of clear plastic over the top. Trace the position of the net cups with a marker to see where the plants will be.



Plug in the pump and slowly open the shutoff valve until the misters spray all of the net cup locations marked on the clear plastic sheet. If the system leaks, or some plants do not receive the nutrient spray (water in this test), then re-engineer the system until all plants receive an equal spray.

Check Your Understanding: Aeroponics

A member of your class is sick and missed the lessons on setting up the aeroponic system. Your teacher has asked you to draw a diagram and explanation for how the aeroponics system works, so the student who has been sick can catch up with the rest of the class.

In the space below, draw a diagram of an aeroponics system. The diagram should include labels for the reservoir, growing chamber, mister nozzles, net cups, pump, and all of the tubing. Use arrows to show which way the nutrient solution, water and materials flow through the system.

Diagram

In a few sentences explain how the aeroponics system operates.

Explanation

Will the Growing Chamber be Dark?

Removing more than 60% of the lid will allow light to leak through and may damage the roots. Perform the following calculation to find out what percent of the lid is removed by drilling holes.

1. Calculate the area of the circles you will be cutting out. (The formula for the area of one circle is below. In the formula, "r" is the radius of the circle (equal to ½ of the diameter); and π = 3.14.)

Area of Circle = $\pi\, r^2 = 3.14 \times r^2$

2. Calculate the area of the lid that will cover the inside of the growing chamber.

Area of Lid = Length x Width

3. Divide the area of all of the circles by the area of the lid to find the percentage that must be removed by drilling circles.

$$\frac{\text{Area of circle}}{\text{Area of lid}} = \_\_\_\_\_\_\_\_\_\_ \text{ X } 100$$

Show all of your calculations below.

The percentage of the lid that is removed by drilling is _____ %

Will the lid be strong enough? (less than 60% removed) YES? ___ NO?___

What's the Big Idea?

Courtesy of Korbin Shoemaker

The most important thing to keep in mind is that your hydroponic system is not just a collection of parts. It is a **system** in which all the parts work together to achieve desired results. Changing one part of the system will affect all the other parts of the system.

The following sentence frames are intended to help you think about your system. Fill in the blanks with your ideas. (Connections do not have to be physically connected.)

Name 8 parts of the Aeroponics System: 1.________________ 2.________________ 3.________________ 4.______________ 5.________________ 6.________________ 7.________________ 8.______________
What will happen if one of these parts breaks down?
Name a different hydroponic system and three or four of its parts.
What is a complicated system in nature? What makes it Complicated?
What is a complicated system created by an engineer? What makes it complicated?

Name______________________ Date______

KSB 3B

Engineer an Ebb and Flow System

Big Idea: Systems have parts that work together to achieve desired results.

Image Courtesy of Cary Sneider

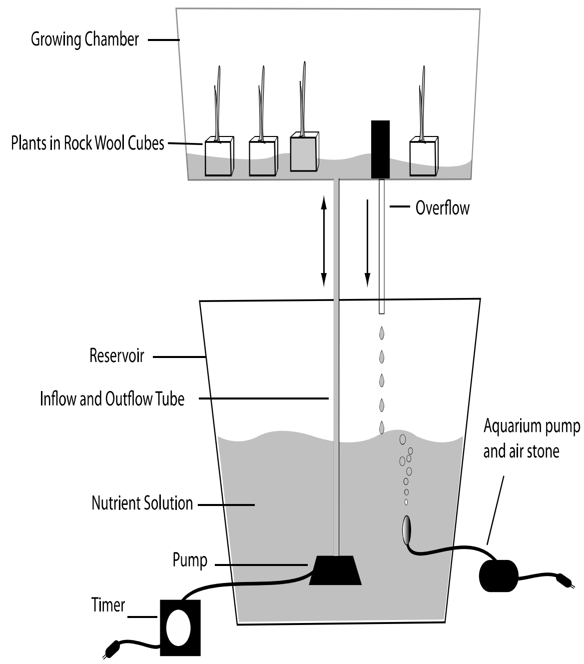

Image Courtesy of Cary Sneider

Like cars, airplanes and houses, hydroponic systems are made of many parts that do very little on their own, but accomplish something quite remarkable when assembled and properly maintained. They can be used to grow food! The system that you have been assigned to build works by spraying the roots of plants with a ***nutrient solution***—water with dissolved minerals that plants need to survive.

When you finish this KSB you will be able to answer the following questions:

- ✓ What is a system?
- ✓ How does an Ebb and Flow system function?
- ✓ What are the inputs, outputs, and goals of an Ebb and Flow system?

A. Introducing the Ebb and Flow System



Hydroponics is a way to grow food that uses less land and much less fresh water than soil farming. As a member of our engineering department at Fresh Food Engineers you will learn to design, build, and maintain an Ebb and Flow system.

In the ebb and flow system bulbs or seeds are placed in Rockwool cubes. Rockwool retains water and supports the plants as they grow.

A pump is submerged in the nutrient solution. It is controlled by a timer so that it turns on and off every few minutes. When the pump is on it floods the growing chamber. An overflow fitting is placed so the plants are not covered by the nutrient solution—just their roots. When the pump is turned off the nutrient solution drains back into the reservoir.

Your challenge is to design and build an ebb and flow system that will:

a) Support the plants so they do not fall over.

b) Provide the nutrients that the plant needs for growth.

c) Have no leaks.

d) Use the materials that are provided, as shown on the next page.

Work together as a team to make decisions and accomplish these tasks. But everyone on the team must create their own drawings and answer all questions.

Points to Ponder: What Is a System?

The idea of a system is very important in engineering. You can't design, build, or fix anything at all complex without understanding it as a system.

A *system* is a group of related parts that move or work together to accomplish a desired result.

Cary Sneider

Steve Haner

Is the image **above** a system? Yes___ No___

Is the image at **right** a system? Yes___ No___

How do you know?

____

Systems have goals (the desired result), resources (such as the materials that go into the system and the energy sources used), processes (events that go on inside the system) and outputs (the actual result). For hydroponic systems, the goal is to grow plants, and the resources include light, air, and nutrients.

What is the goal of the ebb and flow system on the previous page?

Systems also have subsystems, which are smaller systems made from related parts. The goals of subsystems contribute to the goal of the larger system.

What are two of the main subsystems of the ebb and flow system?

The ___________________________ and the ____________________________

B. Tools and Supplies

- Check to see if you have all of these supplies. (Tools are not shown in this list.)
- Put a checkmark next to the name of each item as you identify it.
- If you are missing anything ask your teacher about it.

Item	Quantity	Size	Item Description	Image
Flood Tray	1	10 gallon	10 Gallon Tote (or equivalent) -Used as Growing Chamber for Ebb & Flow	
Reservoir	1	18 gallon	18 Gallon Tote (or equivalent) -Used to contain nutrient solution, pump and (for E&F) air brick.	
Power strip	1	115V 6 outlet	6 Outlet Power Strip (or equivalent)	
Water Pump	1	115V 250 g/h	Active Aqua 250 Gallons Per Hour	
Aquarium Pump and air stone	1	115V	Airpump 3.2 L	
1/2" Black Tubing	1	1/2"x 25 ft	1/2" Inside Diameter Black Tubing	

Item	**Quantity**	**Size**	**Item Description**	**Image**
1/2" Bulkhead Barbed Fitting	2	1/2"	1/2" Bulkhead Barbed Fitting	
Bulkhead Screen Fitting	1	1/2"	Bulkhead Screen Fitting	
Bulkhead Screen Fitting Extender	1	1/2"	Bulkhead Screen Fitting Extender	
Rubber Gromet	1	0.625”	Use to avoid leaks at the bottom of the growing chamber	
Rockwool Cubes	1	3"	Rockwool cubes 3"x3"x2.5" 8-pack	
Grow-lights	1	115V	T5 Grow Light 2ft bulbs 6500k	
Analog Timer	1	115V	24hr grounded timer for light	
Analog Timer	1	115V	15 minute grounded timer for pump	

C. Step 1 Ensure the Growing Chamber Drains

Place the growing chamber and reservoir on the platform you designed.

You will need to make sure that the nutrient solution drains completely into the reservoir when the pump turns off. That will ensure the roots do not rot and algae does not build up inside the growing chamber. So, your first task is to figure out how to arrange the tray so that happens. This could be done with wedges of wood or a simple framework that might be adjustable. Your teacher will advise you on what materials you can use.

Discuss this problem with your teammates. Below sketch at least two ideas for how to ensure the growing chamber drains completely—and be able to adjust it if necessary.

1st Draining Design	2nd Draining Design

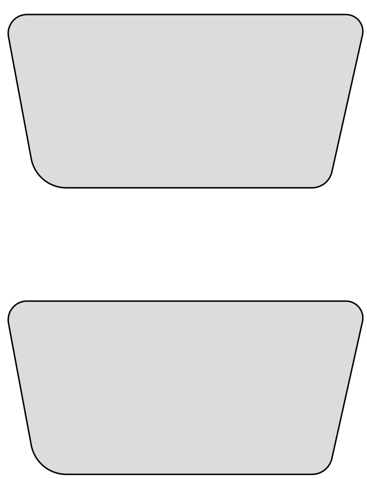
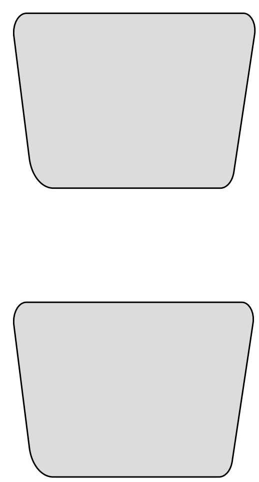
Work with your teammates to decide on the simplest way to ensure the growing chamber will drain. Show your group's decision to the teacher. When you have the teacher's permission, go ahead and set up the growing chamber as you planned.

D. Step 2 Design the System

Look at the diagram of the hydroponic system on page 2. Notice how the two parts of the system are connected.

On a separate sheet of paper, sketch the side view and front view showing the tubes that run between and inside of the two parts of your hydroponic system. When you are satisfied with your design, draw the tubes on each of the two diagrams below

On the diagram show the dimensions, in inches, for the length of each tube. Add a certain amount to the length to allow for the tee fittings.

Side View of Ebb & Flow System	End View of Ebb & Flow System
	

A hole in the bottom of the growing chamber for the drain will need a bulkhead barbed fitting in a rubber gromet, so the tub does not leak. Show these in your drawings.

You will also need a hole in the side of the reservoir for the power cord, and another for the air stone. Show where they will be located.

When you are finished, show the teacher your sketches. When your teacher approves your design, you can start building.

Add the fittings to your drawing. The Bulkhead Screen Fitting and Extender acts as an overflow to keep the solution from flowing over the walls of the tote.

E. Step 3 Build and Test the System

Safety Note: Before you start building be sure you are familiar with all of the safety rules your teacher has provide for the use of tools.

Measure and cut the lengths of the ½" tubing you will need.

If you have difficulty slipping a tube over the outlet of the pump, use the hot glue gun nozzle to gently warm the end of the tubing to make it soft. **Safety Note**: **Do not touch the nozzle of the glue gun or the heated end of the tubing**!

To determine the drill size that you will need to drill the two holes at the bottom of the growing chamber, measure the diameter of the threaded section of the Bulkhead Barbed Fitting (the part that passes through the bottom of the Growing Tray and connects to the tubes.) Record that diameter here: ______

Find the hole saw (or step drill) that is same size as the above dimension or very slightly larger.

Assemble the entire system. Then pour about three to four gallons of water into the reservoir and test it as shown below. Check to see if there are any leaks. If there are, pour the water out, and re-seal the fittings using silicon calk or a hot glue gun.

Once all leaks are fixed plug in the pump and observe to see if it floods the growing tray. Flood until the water reaches the overflow and starts to flow out.

Turn off the pump and observe how long it takes for all of the water to drain out of the growing chamber.

If you encounter any problems, pour out the water, dry the components and re-engineer as needed.

Explain the Ebb and Flow System

A member of your class is sick and missed the lessons on setting up the Ebb and Flow system. Your teacher has asked you to draw a diagram and explanation for how the Ebb and Flow system works, so the student who has been sick can catch up with the rest of the class.

In the space below, draw a diagram of an Ebb and Flow system. The diagram should include labels for the: reservoir, growing chamber, Rockwool®, pump, and all of the tubing. Use arrows to show which way the nutrient solution flows through the system..

Diagram

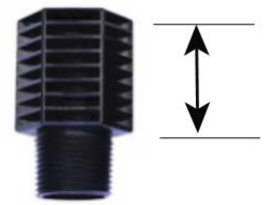
In a few sentences explain how the Ebb and Flow system operates.

Explanation

How Long Will It Take To Reach Overflow?

Timing is very important in the ebb & flow system. The pump must be left on long enough to at least reach the top of the overflow. The following will help you calculate how long that will be.

1. Measure the height of the overflow (Bulkhead Screen Fitting with extender) that will stand above the bottom of the growing chamber after it is filled. Write the height here in inches.

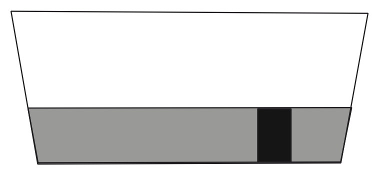


Height of Overflow (H) = ___________ inches

2. Measure the length and width of the inside of the growing chamber.

Width (W) = ____________ inches   Length (L) = ______________ inches

3. Calculate the approximate volume of nutrient solution when the growing chamber floods to the top of the overflow.



Volume (V) = L x W x H

V = _________inches x ________inches x ________ inches = ________ cubic inches

4. How many gallons is that? 1 gallon = 231 cubic inches

V (in gallons) = $\frac{\text{Volume in cubic inches}}{231}$ = _________ Volume in gallons

5. If the nutrient solution is pumped into the growing chamber at the rate of 4 gallons per minute, about how many minutes will it take for the level of nutrient solution to reach the overflow? _______________ minutes.

The length of time that the pump is on must be at least that long.

What's the Big Idea?

The most important thing to keep in mind is that your hydroponic system is not just a collection of parts. It is a **system** in which all the parts work together to achieve desired results. Changing one part of the system will affect all the other parts of the system.

Courtesy of Korbin Shoemaker

The following sentence frames are intended to help you think about your system. Fill in the blanks with your ideas. (Connections do not have to be physically connected.)

Name 8 parts of the Ebb and Flow System: 1.________________ 2.________________ 3._______________ 4.______________ 5.________________ 6.________________ 7._______________ 8.______________
What will happen if one of these parts breaks down?
Name a different hydroponic system and three or four of its parts.
What a complicated system in nature? What makes it complicated?
What is a complicated system created by an engineer? What makes it complicated?

KSB
4

Name______________________ Date______

Hydroponic Farming

Big Idea: Feedback involves monitoring and adjusting a system to maintain a desired output.

ICourtesy of Korbin Shoemaker

Now that you have set up your hydroponic system it's time to start farming! As you'll see, farming involves more than just planting seeds. You'll need to check on your plants' progress frequently. Based on what you observe and measure, you'll need to adjust the chemical composition of the nutrient solution, lighting, and temperature. When you finish this KSB you will be able to answer the following questions:

- ✓ What does it mean to monitor and maintain a system?
- ✓ How can you measure the most important characteristics of a hydroponic system?
- ✓ What do you do when the system is not operating as expected?

A. Prepare the Nutrient Solution

In traditional farming, plants get their minerals from the soil. In hydroponic systems a nutrient solution is added to the water. Keep in mind that the nutrient solution is not "food." It's more like a multi-vitamin with minerals that plants need. Plants make their own food by capturing the energy in sunlight and using it to break up water molecules. They combine the hydrogen atoms from water with CO_2 from the air to form carbohydrates. Plants use the carbohydrates to build stems, leaves, roots, flowers and fruits.

Prepare the nutrient solution as follows:

1. Wipe down the reservoir and growing tray with a cloth that has been moistened with rubbing alcohol. That will kill harmful bacteria. Allow the reservoir and growing tray to dry overnight.

2. Fill the reservoir with eight gallons of clean water. Double-check fittings for leaks before proceeding.

3. Mix the nutrient solution into the water, following directions on the container.

4. Before you plant, measure the pH of the solution. pH is a measure of how acidic a solution is.

5. To test the pH of the nutrient solution, follow directions on the test kit bottle and your teacher's demonstration. You will need to use a pipette, which is a chemical tool for transferring small amounts of liquid. If the pH is too low (too acid) you will add a small amount of the "Up" solution. If too high (too basic) you will add a small amount of the "Down" solution, and retest.

Nutrient Solution

pH Test Kit

Up Solution

Pipettes

Down Solution

6. Different plants require different pH levels to grow best. Use the Internet to look up the pH that your plants need in order to thrive.

B. Planting in the Aeroponics System

1. Check to be sure you have done the following before planting:

___ Constructed your hydroponic system and tested it with water

___ Cleaned the growing tray and reservoir with alcohol

___ Mixed the nutrient solution

___ Tested for pH, and adjusted it as needed so pH is in the recommended range

___ Placed the system near an electrical outlet

2. If you have completed the above checklist, your team will be given:

- 8 Net Cups
- 8 Plant seeds or bulbs
- clay pellets

3. Pour a few clay pellets into each cup.

4. If planting bulbs for onions or garlic, place one bulb in the middle of each cup and gently add clay pellets so the top of the bulb is just below the surface. If you are planting seeds, put 3 or 4 seeds in different parts of the cup so their roots will not become tangled. Place the cups into the holes in the aeroponics system.

5. Place the light 6” above the growing tray.

6. Check the temperature at the top of the net cups. Temperature should not be greater than 25°C (about 80°F). If it is too hot change the position of the light.

7. **Light timing:** Set the programmable timer connected to the lights to be 12 hours on (during the day) and 12 hours off (at night.)

8. **Pump timing:** Start with 15 minutes on, 15 minutes off (repeat continuously). If the environment is very dry the pump should be on longer so the roots don’t dry out. If very humid it should be on less time so the roots don’t rot.

Image Courtesy of Ildar Sagdejev

C. Planting in the Ebb and Flow System

1. Check to be sure you have done the following before planting:

___ Constructed your hydroponic system and tested it with water

___ Ensured that the nutrient solution drains completely when the pump is off

___ Cleaned the growing tray and reservoir with alcohol

___ Mixed the nutrient solution

___ Tested for pH, and adjusted as needed so pH is in the recommended range

___ Located the system near an electrical outlet

2. If you have successfully completed the above checklist, your team will be given:8 Rockwool cubes with seedlings that have already been started. Place the cubes on the bottom of the growing chamber.

3. Place the light 6" above the growing tray.

4. Check the temperature at the top of the Rockwool cubes. Temperature should not be much above room temperature (not be greater than 80° F). If it is too hot change the position of the light.

5. Light timing: Set the programmable timer connected to the lights to be 12 hours on (during the day) and 12 hours off (at night.)

6. **Pump timing:** Start with 15 minutes on, 15 minutes off (repeat continuously). If the environment is very dry the pump should be on longer so the roots don't dry out. If very humid it should be on less time so the roots don't rot. Here's a good place to start:

7. Observe a full cycle to be sure that the growing chamber floods to soak the Rockwool cube (and later the roots,) and that it drains thoroughly. If it does not, re-engineer until it cycles properly.

Image Courtesy of Korbin Shoemaker

D. Collect Data

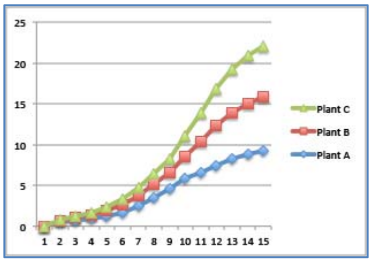
Depending on the kind of plant that you are growing, choose a means for measuring growth. It might be the height of the plant or length of the longest leaf. At least twice a week measure each plant in your system. Record these measurements below, so that you can graph the results when it is time for harvesting. You will then be able to see how the rate of growth has changed.

Your teacher will ask you to measure the pH of the plant water frequently to ensure it is within the normal range of 5.8 and 6.5. Your teacher may also ask you to measure the Total Dissolved Solids in parts per million (ppm) to determine if the solution has the right concentration of minerals. Write these numbers in the third column and record the depth of water in the reservoir in the fourth column.

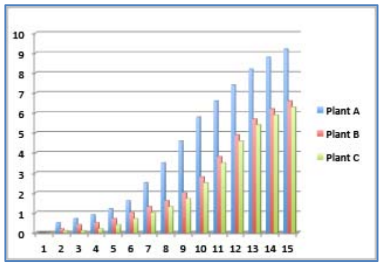
Date	pH	ppm	Depth	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8

Points to Ponder

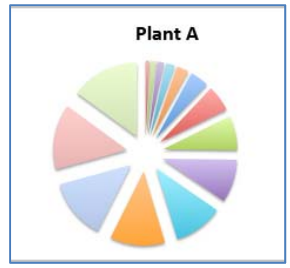
When you harvest your plants summarize the data in a graph. Which kind of chart or graph will best display the data you plan to collect? Circle the kind of graph you think will be best.



Line Chart



Bar Chart



Pie Chart

Summarize Your Results

1. How did the growth rate change from the time you planted to the time you harvested?

____

____

2. Did all plants grow at the same rate? If not, what were the differences, and why do you think those differences occurred?

____

____

3. Based on your graph, how large do you think your plants would grow if you could keep them growing for another week? __________ another month?____________

4. Collecting data about a system's output to make decisions about how to maintain the system is called ***feedback***. In what ways did you use feedback to maintain the health of your hydroponic systems?

____

____

Agricultural Engineering

Just about all the foods we eat have been changed from the wild variety to make them more nutritious and easier to grow. For example, corn was developed by Native Americans at least 5,000 years ago. The wild plant, called *teosinte*, is shown in the image to your right. Native Americans selected seeds from the biggest and best teosinte cobs for planting. They then harvested and selected the best of those to replant, and so on. After many generations, they developed the corn we grow now.

John Doebley

By developing corn and other crops, Native Americans changed the natural plants to better meet their needs. Although they would not have used that term, they acted as **agricultural engineers.** Selecting seeds from the best crops to plant is one method of improving crops. Another method is conducting experiments.

Experiments can be conducted by scientists or engineers. Scientists experiment to test their explanations of natural phenomena. Engineers experiment to see which designs performs better, or to find out how their product works. Here's an example of an agricultural engineering experiment.

1. Decide on an outcome variable. Let's say some agricultural engineers wanted to increase the amount of lettuce that they grew in their hydroponic garden. The first thing they did was to decide how to define "amount." They decided that weight would be the best way to define amount.

2. Decide on an experimental variable. Next the agricultural engineers thought about what may make the biggest difference in the growth rate of their lettuce plants. They decided that pH might make the biggest difference.

3. Decide what to keep constant. A good experiment should test just one experimental variable. In this case the agricultural engineers wanted to find out if pH made a difference in growing lettuce, so they kept all of the other variables the same. Here's a diagram of their experiment.

		
pH = 6.0 8 lettuce plants Aeroponics Average temp = 75°C Lights 12” above plants	**pH = 6.5** 8 lettuce plants Aeroponics Average temp = 75°C Lights 12” above plants	**pH = 7.0** 8 lettuce plants Aeroponics Average temp = 75°C Lights 12” above plants

Images courtesy of Korbin Shoemaker

4. Conducting the Experiment. During the experiment the agricultural engineers made sure that each hydroponic system was given the same amount of nutrients, on the same schedule, so that the experiment would be a fair test of the effect of pH on the growth of the lettuce plants.

5. Drawing Conclusions. When the plants achieved their maximum growth, the engineers harvested and weighed the plants. They made a bar graph of their results and recommended the best level of pH for growing that type of lettuce.

1. Plan an experiment to determine whether the aeroponics system or ebb and flow system is better for growing vegetables.

A. What is the experimental variable?

B. What would your outcome variable be? How would you measure it?

C. What will you keep constant in this experiment?

2. Is agricultural engineering something you may want to do as a career? ___________

If yes, what do you like about it? If not, why not? ______________________________

Think Like an Engineer

Engineering requires good teamwork. That means everyone contributes to the work, everyone's ideas are considered, and each team member behaves respectfully to the other team members. Please circle the number that best reflects your groups' teamwork.

	Disagree									Agree
I contributed fully to our project.	1	2	3	4	5	6	7	8	9	10
I listened to my teammates' ideas	1	2	3	4	5	6	7	8	9	10
I expressed my ideas honestly.	1	2	3	4	5	6	7	8	9	10
My teammates contributed fully to our project.	1	2	3	4	5	6	7	8	9	10
My teammates listened to my ideas	1	2	3	4	5	6	7	8	9	10
My teammates expressed their ideas honestly.	1	2	3	4	5	6	7	8	9	10
I enjoyed working on this project.	1	2	3	4	5	6	7	8	9	10

Check Your Understanding

1. A student is raising tomato plants using hydroponics. The ideal nutrient solution pH for tomato plants ranges from 6.0 to 6.8. The student measures the pH of the nutrient solution and finds that it is 5.0. What should she do?

a. Add a small amount of acid solution until the right pH level is reached

b. Add a small amount of base solution until the right pH level is reached

c. Add equal amounts of acid and base solutions until the right pH level is reached

d. Do nothing, since pH will correct itself as the water evaporates

2. Four students are having an argument about how to compare two different hydroponic systems, A and B, to see which is best for growing onions and garlic. Which method will produce the most useful information about the two systems?

a. Plant garlic in System A and onions in System B.

b. Plant garlic in both System A and System B.

c. Plant onions and garlic in both System A and System B.

d. Plant onions in both System A and System B

3. Joe and Tasha are growing basil in small, homemade hydroponic systems. Each system grows only one basil plant. To explore the effect of the nutrient solution, they grow one plant using the nutrient solution and one plant using just tap water. To improve this experiment they should:

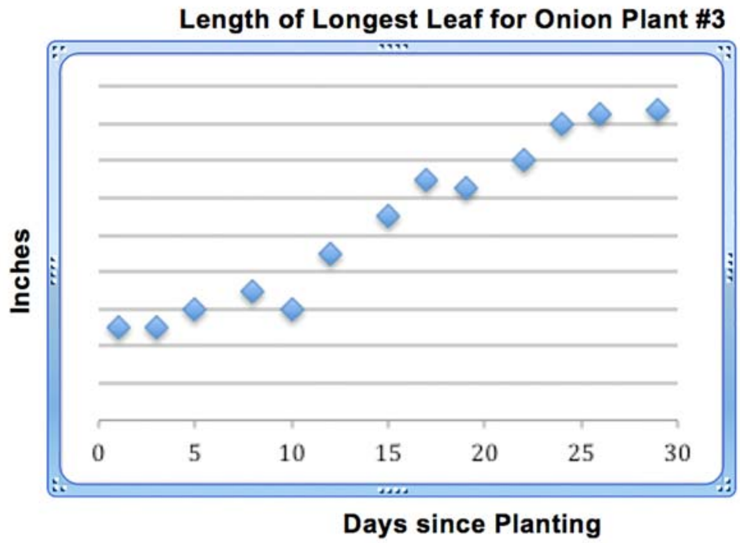
a. Use only one hydroponic cell

b. Increase the pH of the tap water

c. Increase the number of basil plants

d. Use onion instead of basil

4. One group of students measured the length of the longest onion leaf that grew in their hydroponic system several times a month. They plotted the data on the following graph.



If the students want to draw a line on their graph to reveal patterns in plant growth, they should:

a. Draw a straight line between each of the data points

b. Draw a straight line from the data point on day 1 to the data point on day 30

c. Draw a smooth curved line to fit as many of the data points as possible

d. Draw a curved line that touches each of the data points

5. The data point for day 10 in the graph above is lower than expected. What is the most likely reason for that? (Refer to the graph.)

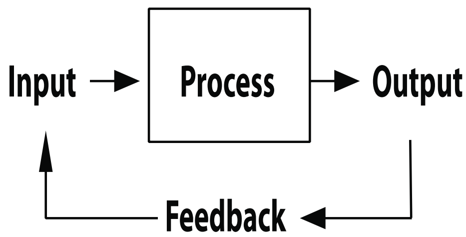
a. The students forgot to water the plants

b. The leaf shrunk a little naturally

c. The students made a measurement error

d. The lighting system was accidentally turned off

What's the Big Idea?



The most valuable commodity to a farmer is not good seeds or fertilizer. It is information about how the crops are doing, and the environment where they are growing. Without information the farmer is powerless to provide what the crops need to survive. The diagram at left shows how the farmer can change the process of growing plants by examining the output for signs of what the plants may need, and changing the input accordingly. Monitoring and changing the system in this way is called **feedback**.

Feedback involves monitoring the output of a process, and adjusting the input so that the entire system accomplishes a goal.

When you are monitoring your hydroponic system, what information are you collecting?
How will that information help to change the input to your hydroponic system?
See if you can think of one other situation in life where feedback is used.

KSB
5

***Name*______________________ *Date*______**

Modeling with Computer Aided Design (CAD)

Big Idea: Models are a powerful means for visualizing, analyzing, and predicting the behavior of systems.

Courtesy of Freedesignfile.com. Creative Commons

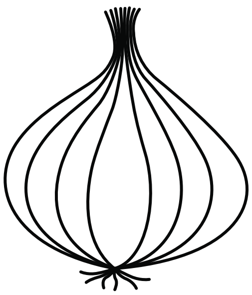
To complete your training as a valued employee of Fresh Food Engineers we would like you to learn to use Computer Aided Design software to make 3D models. These are usually called CAD programs. CAD allows you to create a drawing that you can manipulate onscreen. Because you can change and manipulate the drawing, it is a powerful means for visualizing, analyzing, and predicting the behavior of a system.

There are several different software programs that you can choose from, which are free and can be downloaded from the Internet. The one we have chosen to use is SketchUp, but any CAD program will do.

- ✓ When you complete this KSB, you will show your ability to use CAD by designing an apartment building with at least one wall that has no windows.
- ✓ Later you will show your increased ability to use CAD by adding a vertical hydroponic system to your 3-D model.
- ✓ Finally, you will show your ability to import ready-made 3-D objects from a graphics library.

What Is a 3D Model?

Look at the three images of an onion below. They are very different, although they are all representations of an onion.



A

B

C

People make different types of representations for different purposes. Which representation of an onion (A, B, or C) would you use for the following purposes?

To hang on the wall in a restaurant. _____

To advertise onions at a grocery store. _____

To illustrate a botany lab notebook. _____

There are no right or wrong answers to the above questions. It's a matter of personal preference. However, for some purposes, one type of drawing may be better than others. CAD software is used by engineers to produce 3D models. Here's what you can do with a computer-based model of an object:

- You can make a set of 2D drawings, with dimensions, that can be used to manufacture the object.
- You can display the object as a 3D drawing, which you can move around the screen and look at from different points of view.
- You can make objects with certain exact sizes, shapes, colors and textures.
- If you make a mistake you can correct it easily without redrawing everything.
- You can easily send your drawings to someone else via email.

View one or two videos about CAD on the Internet. Your teacher may have one for you to see, or you can use a search engine to find videos about "Computer Aided Design."

Let's Get Started!

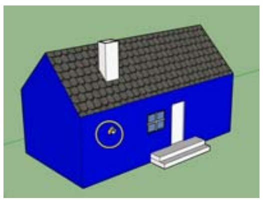
There are several CAD programs available. The one we have chosen for this course is SketchUp, since it is free and easy to learn; but any CAD software is fine. If SketchUp is not already on your computer you will need to download it at the following website:

VIDEO LINK INSERT [http://www.sketchup.com/products/sketchup-make]

One of the teachers who helped to develop this unit has produced video tutorials to help you learn to use SketchUp. Download these videos at the following website:

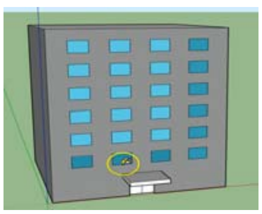
VIDEO LINK INSERT [NEED TO INCLUDE STEVE HANER'S VIDEOS]

If possible, open a window for a video and another for the software so you can stop the video after seeing each step and try it for yourself.



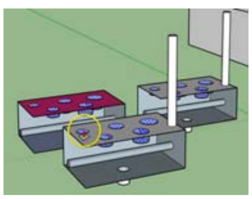
1st SketchUp Tutorial: Push and Pull Basic Shapes

In this introductory video you 'll learn how to use a few basic commands to create and change a shape, then "paint" it the color you choose.



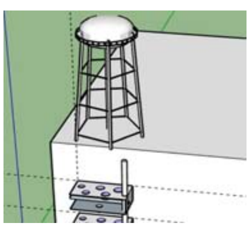
2nd SketchUp Tutorial: Design a Building

Learn how to create and copy elements to make them all alike, such as the windows on this apartment building.



3rd SketchUp Tutorial: Groups and Components

This tutorial will illustrate how to use groups and components to make different objects and how to rotate individual pieces of the model.



4th SketchUp Tutorial: Moving and Rotating Models

The last tutorial illustrates how to rotate individual parts and assemble them into a complete system. You'll also learn about importing pre-made parts and even whole objects that are available from the online SketchUp Warehouse.

Practice Using SketchUp

Your next assignment is to design the outside of an apartment building. Later you will design a vertical hydroponic farm on one or two walls of the building..

- Observe buildings in your neighborhood, such as apartment buildings like those in the pictures on the right, to include in your design.
- Start with the ground floor. Imagine how many apartments might be on one floor, and how big they would be. Use that information to create the size and shape of the ground floor.
- Assume there will be about 10 feet per story. Decide how many stories you want to draw. It's best not to draw too many or it will take too long to copy items like balconies and windows. Six to eight stories is fine.
- Include one or two walls with no windows, like those shown on the buildings at right.
- Add windows, balconies, and any other features you think would be interesting. Try to make the building a place in which you might like to live.
- Save your building design, as you will need it later.

Image Courtesy of Cary Sneider

Image Courtesy of Cary Sneider

Image Courtesy of Cary Sneider

Tradeoffs. As you design your building you'll need to make some tradeoffs. For example, people like to hang pictures on their walls. They also like to have natural light. More windows means less space for pictures; more space for pictures means less natural light. Finding the right balance is a tradeoff. Name two other tradeoffs involved in designing an apartment building:

Check Your Understanding

Inspect Your Building

Designing an apartment building is not an easy task. Check your work against the criteria listed on the previous page. Then exchange with a teammate and score each other's work.

	Maximum Points	Your Score	Teammate's Score
Width vs, Height of Bldg,. Is the size and shape of the building reasonable for number of apartments you envision in each story?	25		
Number and height of floors. Have you allowed 10 feet per story? Do all of the apartments have some windows?	25		
Blank Walls vs. Windows. Have you made a reasonable tradeoff between blank external walls and windows to allow for a vertical farm?	25		
Attractive. Is the building sufficiently attractive that you'd like to live there?	25		
Pre-made objects. Did you import a pre-made object into your building? If yes, give yourself a bonus of 25 points and list it here:__________	25		
Total	125		

How easy or difficult was it to learn how to use SketchUp? (Circle one)

Very Easy Easy Medium Difficult Very Difficult

Is there anything about using SketchUp that you still need help with? Please describe.

Points to Ponder

CAD or Hand Drawing?

No single solution works for everything. Consider the following situations where sketching on paper or CAD drawing is maybe preferred. Circle the best answer for each case. Then explain why you made that choice.

1. Accurately draw parts to see if they will fit together. Explain:	CAD? Or Hand Drawing?
2. Get ideas down on paper quickly before you forget. Explain:	CAD? Or Hand Drawing?
3. Provide a drawing for a device to be manufactured. Explain:	CAD? Or Hand Drawing?
4. CAD is one tool that you can use to create 3D Models. Search the Internet to find at least 3 careers that use 3D modeling. What are they?	

What's the Big Idea?

In KSB5 you have been creating 3D models using CAD software. Unlike a drawing, a virtual 3D model can be inspected from different points of view by rotating around it. You can also change the model easily and then return it to its original state. That's why CAD software is so useful in design.

There are other kinds of models besides CAD drawings. A model is any representation of the real world that emphasizes certain features and ignores others. A model can be a diagram, a physical replica, or a computer simulation. A model can represent a natural system or a designed system.

1. **a.** What is one feature of a building that a CAD model can represent well? b. How is it helpful to include that feature in a model?
2. a. Which features of a building does a CAD model ignore? b. How is it helpful to ignore those features?
3. Car designers build small physical replicas of new ideas for cars. How might they use such models to improve the cars' performance and safety?
4. The BIG IDEA for this KSB is that "Models are a powerful means for representing, analyzing, and predicting the behavior of systems." What does this statement mean to you?