Grade: 9-12	Topic: Hydroponics	Lesson (Number/Title): Building and Assessing an Indoor Vertical Hydroponics Farm

Brief Lesson Description:

Students will be introduced to the concepts of indoor vertical gardening and hydroponics as solutions to challenges facing food production in parts of our world. Through the study of various hydroponic growing methods, students will gain an understanding of the variables that prove most critical for the success of the system. They will also develop an appreciation for how to monitor and control these variables while utilizing hydroponic growing methods. Students will design their systems to house several different species of plants and fine tune their variables to suit the needs of their chosen crops. Finally, students will compare the different hydroponic methods to traditional farming in soil and consider the pros and cons of each style. Students will analyze their results based on the metrics of energy usage, water consumption, and total cost per gram of yield.

Performance Expectations:

HS-LS1-3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon 5. among the biosphere, atmosphere, hydrosphere, and geosphere.

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

HS-ESS3-3. Create a computational simulation to illustrate the relationships among the management of natural resources, the sustainability of human populations, and biodiversity.

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Specific Learning Outcomes:

- Students will identify the resources that plants require from their environment in order to survive.
- Students will compare qualitative and quantitative data to determine which design is most effective.
- Students will communicate their results with one another in order to identify the aspects of their models that should be carried forward and those that should be eliminated.
- Students will identify which crops are most successful in a multi-species system.
- Students will perform a cost analysis for growing hydroponic crops vs traditional soil-based methods.
- Students will analyze the carbon footprint of locally grown hydroponic produce vs produce that must be shipped from distant growing locations.
- Students will use the graphical representation of data to draw conclusions about their designs and growing methods.

Narrative/Background Information:

Background for Teachers:

One of the many challenges facing an ever growing human population is the problem of food production. Suitable farmland is being diminished by urban expansion. Unpredictable climate patterns are shortening or making growing seasons more harsh. Irrigation concerns related to scarcity or contamination are putting a premium on clean water as an accessible resource. Science and engineering will be called upon to combat these concerns. A new wave of indoor vertical farms is allowing us to produce food in otherwise inhospitable growing environments. Congested urban cities; oppressive desert and arctic climates; even the prospect of growing food on orbiting space stations or other planets is within reach.

As part of this lesson, students will gain an appreciation for the resources necessary to grow crops, the variables that must be controlled, and the obstacles involved with growing in such remote locations. The focus of this study will be on resource consumption, carbon footprint, and economics of applying indoor vertical hydroponic farms vs standard soil-based agriculture.

Teachers Preparation:

- If choosing to run a supplemental wick system (Model C), 2L plastic bottles should be collected ahead of time, rinsed, and have their labels removed. Retain the caps.
- PVC pipe, fittings, and glue may be needed if you wish to build Model C in the tutorial.
- The Deep Well Culture , or DWC (Model D), will require a specialized components. These can be purchased through a vendor of your choosing or through the provided retailer.
- It is strongly recommended that you do not use a greenhouse for your system. Temperature control in these environments will prove cost-prohibitive. Grow light recommendations have been made in the attached bill of sale.
- If you intend to start from seed, be sure to have all necessary seed starting equipment prior to introducing the lesson.
- You should select 3-4 crops from the following list and acquire seeds:
- Seeds should be sewn at least 2-3 weeks in advance of implanting them into their systems. If you intend to start the soil control group in their own pots, do so at the same time that you prepare the hydroponic rockwools.
- Germination period should be taken into consideration when seeding so that mature crops may be grown concurrently.
- Any students that handle the rockwools should wear non-latex gloves, protective eye wear, and should avoid shredding the material so that it is not inhaled.
- Designate a spot in your classroom that will provide ample light for your plants or prepare a growing area that will be equipped with indoor grow lights. You may wish to purchase or construct an apparatus that will act as a shelving system for your vertical growing environment. Be sure to select strong building materials as the water in the reservoirs can become quite heavy.

- Hydroponic solutions will need to be prepared with the appropriate pH and nutrient concentrations. Instructions will be included in the tutorial series. Proper skin and eye protection should always be used when handling liquid nutrients or pH adjustment solutions.

Prior Student Knowledge:

- Students should have an understanding of photosynthesis in terms of its reactants and products.
- Students should grasp sound experimental design and be able to apply the concepts of experimental vs control groups, independent vs dependent variables, and limiting confounding variables.
- Data tables should be able to be converted into line graphs for analysis and read for relationships between the independent and dependent variables.
- Unit conversions should be able to be executed by manipulating simple proportions.
- Proper research procedures should be covered for using online search engines and polling information sources for their validity. Students will need to research suitable air and water temperature, pH, EC, and photoperiod for the selected crops.

Science & Engineering Practices:

Planning and Carrying Out Investigations

Planning and carrying out in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. (LS1-3)

Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (LS1-3)

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. (LS1-5)

Use a model based on evidence to illustrate the relationships between systems or between components of a system. (LS1-5), (LS2-5)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. (LS2-7), (ESS3-1), (ESS3-4), (ETS1-2), (ETS1-3)

Design, evaluate, and refine a solution to a complex real-world problem, based on scientific

Disciplinary Core Ideas:

PS3.D: Energy in Chemical Processes

The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. (LS2-5)

LS1.A: Structure and Function

Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. (LS1-3)

LS1.C: Organization for Matter and Energy Flow in Organisms

The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (LS1-5)

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. (LS2-5)

Crosscutting Concepts:

Stability and Change

Feedback (negative or positive) can stabilize or destabilize a system. (LS1-3), (ESS3-4)

Much of science deals with constructing explanations of how things change and how they remain stable. (LS2-7)

Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (ESS3-3)

Energy and Matter

Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (LS1-5)

Systems and System Models

Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions— including energy, matter, and information flows—within and between systems at different scales. (LS2-5)

Cause and Effect

Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (ESS3-1)

Influence of Science, Engineering, and Technology on Society and the Natural World

Engineers continuously modify these technological systems by applying scientific knowledge and

knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations. (LS2-7), (ESS3-4), (ETS1-2) Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (ESS3-1) Evaluate a solution to a complex real- world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations. (ETS1-3) **Engaging in Argument from Evidence** Engaging in argument from evidence in 9– 12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. (ESS3-2) Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations). (ESS3-2) **Using Mathematics and Computational Thinking** Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. (ESS3-3) Create a computational model or simulation of a phenomenon, designed device, process, or system. (ESS3-3) **Asking Questions and Defining Problems** Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. Analyze complex real-world problems by specifying criteria and constraints for successful solutions.	**LS2.C: Ecosystem Dynamics, Functioning, and Resilience** Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (LS2-7) **LS4.D: Biodiversity and Humans** Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). (LS2-7) Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. *(Note: This Disciplinary Core Idea is also addressed by HS-LS4-6.)* (LS2-7) **ESS3.A: Natural Resources** Resource availability has guided the development of human society. (ESS3-1) All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (ESS3-2) **ESS3.C: Human Impacts on Earth Systems** The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources. (ESS3-3) Scientists and engineers can make major contributions by developing technologies that produce less pollution	engineering design practices to increase benefits while decreasing costs and risks. (ESS3-2), (ESS3-4) Modern civilization depends on major technological systems. (ESS3-3) New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (ESS3-2), (ETS1-1), (ETS1-3) **Science Addresses Questions About the Natural and Material World** Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. (ESS3-2) Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. (ESS3-2) Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. (ESS3-2) **Science is a Human Endeavor** Science is a result of human endeavors, imagination, and creativity. (ESS3-3)

	and waste and that preclude ecosystem degradation. (ESS3-4) **ETS1.A: Defining and Delimiting Engineering Problems** Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (ETS1-1) Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (ETS1-1) **ETS1.B: Developing Possible Solutions** When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental impacts. (LS2-7), (ESS3-2), (ESS3-4), (ETS1-3) **ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (ETS1-2)	

Possible Preconceptions/Misconceptions:

- Plants require soil in order to perform photosynthesis.
- Light must come from the sun in order for plants to get enough energy to grow.
- Plants use oxygen from the atmosphere around them.
- All acidic substances are harmful to living things.
- The more nutrients given to a plant, the more successful it will be.
- Soil must be packed tightly around the root base of a plant.
- Radiation from the sun is safe in space.
- All plants require the same amount of fertilizer/nutrition.
- Hydroponics is too expensive to employ on a large scale for the purpose of food production.

LESSON PLAN: 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions

Students will be engaged in a discussion about the concept of establishing an extraterrestrial space colony and terraforming another planet. Some may wish to show a short video clip from the film “The Martian” to stimulate interest. The opening focus should be on the basic necessities required by humans making this leap. Food, air, and water will all be viable responses.

This should be linked back to the role of plants and the importance of establishing successful crops in these new living environments. Emphasis should be placed on their being the start of the food chain, their ability to purify the air, and their ability to recycle both organic and water wastes produced by humans.

The discussion may now be directed toward the challenges in supporting a successful crop in these environments. Students should be asked about an terrestrial analogs to these growing challenges. Responses may range from those with harsh temperatures (desert/arctic), to those with severe drought, to those that lack fertile soils or space to accommodate agriculture (urban environments).

What will plants require and why will it be difficult to supply these things in these locations? What makes it difficult to import these resources?

EXPLORE: Lesson Description -

Activity 1 - Research

1. After the opening discussion, students will be asked to complete the fields on their worksheet related to the needs of plants and the difficulties for accommodating them in space or those “food deserts” here on Earth. Areas of emphasis will include water, air, light, nutrients, and a suitable growing medium. Students may be required to use an online resource to complete this section. Answers should be reviewed and discussed.
2. A brief discussion about indoor vertical hydroponic farming should follow. Points of emphasis should include a small spatial footprint, ability to grow without soil, use less water, avoid contaminants and pestilence associated with traditional soil (insect, fungus, pollutants), and accelerated growth rates.
3. Introduce students to the various systems they will be building and observing over the coming weeks (wick, drip, and deep well systems). They should be helped to understand the mechanism by which each works. This will be covered in the accompanying tutorials.

Activity 2 - Seeding

1. Students will make selections from the recommended list and use their research to determine a seeding schedule based on germination rates. Students should also focus their background research on depth of sewing, optimal air and soil temperatures, and photoperiods to help choose a range that will support all crops.
2. Seeds should be sewn into rockwools according to their research and transferred into the seed nurseries. Parallel crops should be sown in soil and kept in a separate growing environment

Activity 3 - System Design and Construction

1. While germination and seedling growth is taking place, students should be placed into design teams to create one of the desired systems following the tutorials provided. The worksheet will walk them through making decisions about medium, wicks, reservoirs, and plant thinning.
2. The instructor may wish construct a shelving system for the DWC units. The number of buckets/trays is up to your discretion based on space and light limitations.
3. Table two should be completed in the worksheet to give students an opportunity to review plant anatomy and help understand how their indoor farm will accomodate them.

Activity 4 - Variable Monitoring and Control

1. During the course of the grow, students should make both quantitative and qualitative observations about their systems as well as their samples in soil. Daily air and water temperature, pH, plant height, leaf number, and general appearance will be recorded. Nutrient reservoirs should be changed bi-weekly.

2. It should be noted that top watering will be necessary on a daily basis for the first 7-10 days after transplant into the new systems.
3. Through the use of supplemental data-collecting equipment, the volume of water and kWh consumed should be closely tracked and documented.
4. Worksheets will guide students toward creating line graphs for the measurable variables. Discussion questions will help students to evaluate their design.
5. Communication between lab groups will take place during this process for the purpose of comparison and design iteration for future endeavors.
6. Students will communicate via FlipGrid on a weekly basis to update each other and international peers about their progress.

Activity 5 - Harvest and Yield Efficiency

1. Upon harvest, students will weigh their total yield in grams.
2. Students will use collected data relating to water and power consumption to determine L/g of water and kWh/g of electricity consumption.
3. Students will research the overall cost of these two utilities to determine the cost in USD / g of yield.
4. These numbers should be compared to their soil control groups.

Activity 6 - Carbon Footprint Extension

1. Based on Yield efficiency metrics, students will research how this translates into carbon dioxide emissions. Figures will be provided for common imported crops for the purpose of comparison.

Materials Needed:

- Empty 2L plastic bottles (or size of your choosing), caps pre-drilled and cuts started with a hobby knife
- PVC pipe cut to length and fittings(optional if choosing design C)
- See bill of sale and tutorial for Deep Well requirements.
- ¼ inch braided nylon rope
- Aluminum foil
- Spray paint (optional)
- Spray adhesive (optional)
- Scotch tape
- Pots/containers for plants grown in soil
- Potting soil
- Various hydroponic growing media (perlite, coconut coir, hydroton, rockwool)
- Seedlings (or seeds if starting on your own)
- Hydroponic nutrients (see bill of materials)
- pH adjustment solutions (see bill of materials)
- Thermometers
- Rulers
- Litmus paper or digital pH probe for pH testing
- Flow meter attachment for fill hoses
- Kill A Watt energy meter for electrical consumption

Probing or Clarifying Questions:

1. What makes topsoil different from sand and gravel? Where does this organic material come from?
2. Why do some terrestrial environments or space lack these materials in their dirt?
3. What resources would be difficult to come by when growing plants in these locations?
4. What challenges would colonies face while trying to grow a crop in in these locations?
5. What benefits besides being a food source would plants provide?
6. How is reservoir volume related to temperature and pH stability?
7. How is the volume of water consumed by hydroponic plants compare to those grown in soil?

8. How does the yield from a hydroponic garden compare to that from soil?
9. How do the growing rates of these two methods compare to one another?
10. How do the carbon footprints of indoor hydroponic gardens and imported soil-based produce compare?
11. What are the major costs involved with indoor hydroponic gardening and how can these systems be made to be more cost effective?

EXPLAIN: Concepts Explained and Vocabulary Defined

Teacher:
- Asks for justifications (evidence) and clarification from students to provide evidence for the variables they selected for in their models.
- Formally provides definitions, explanations, and new labels
- Vocabulary: Hydroponics, capillary action, pH, electrical conductivity, parts per million, concentration, photoperiod, carbon footprint

Students:
- Uses their recorded observations in explanations
- Listens critically to others' explanations.
- Analyze graphical relationships to determine the relationships between variables
- Interpret data to determine flaws in their experimental design
- Iterate their design for future testing and increased efficiency

ELABORATE: Applications and Extensions

Teacher:
- Refers students to existing data and evidence and asks: What do you already know? Why do you think…?

Students:
- On a blank sheet of paper, encourage students to draw and label their creation while in use.
- Regroup students with new partners and have students check for understanding with their peers and compare results.
- Students will use FlipGrid to communicate results and offer suggestions for design revisions.

EVALUATE: Formative Monitoring (Questioning / Discussion):

Teacher:
- Asks open ended questions such as: Why do you think….? How would you explain…? What evidence do you have?

Students:
- Answers open ended questions by using observations, evidence, and previously accepted explanations.
- Asks related questions that would encourage future investigations.
- Students will communicate with peer groups in different countries to compare the crops they selected and the success in their design.

Summative Assessment (Quiz / Project / Report): End of Unit group quiz and virtual discussion with international partner classes.

Reflection:

Ask students to observe these concepts in real world applications and explain them using support from their recorded observations.

Common Core State Standards Connections:

ELA/Literacy -

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-ESS3-1)

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. *(HS-LS1-3)*, (HS-LS2-7)

WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and over reliance on any one source and following a standard format for citation. *(HS-LS1-3)*

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-LS1-5)*

RST.9-10.8 Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. *(HS-LS2-7)*

RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-ESS3-1)*, *(HS-ESS3-2), (HS-ESS3-4), (HS- ETS1-1)*

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-LS2-7), (HS- ETS1-3)*

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.(HS-LS2-7), *(HS-ESS3-2), (HS-ESS3-4),* (HS- ETS1-1), *(HS- ETS1-3)*

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. *(HS- ETS1-1), (HS- ETS1-3)*

Mathematics -

MP.2 Reason abstractly and quantitatively. *(HS-LS2-7), (HS-ESS3-1), (HS-ESS3-2), (HS-ESS3-3), (HS-ESS3-4), (HS- ETS1-1), (HS- ETS1-3)*

MP.4 Model with mathematics. (HS-ESS3-3), *(HS- ETS1-1), (HS- ETS1-2), (HS- ETS1-3)*

HSN.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(HS-LS2-7), (HS-ESS3-1), (HS-ESS3-4)*

HSN.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. *(HS-LS2-7), (HS-ESS3-1), (HS-ESS3-4)*

HSN.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-LS2-7), (HS-ESS3-1), (HS-ESS3-4)*

Notes for Future Reference: