Application 1: Designing, constructing, and reengineering a system

PROJECT FEED 1010
Institute for Systems Biology

THE BIGGER PICTURE

Using mathematics and computational analysis, students design aquaponic systems to be part of the solution to food insecurity in a developing country. In this NGSS STEM activity and optional lab, students can either use real data collected from an aquaponic system at Institute for Systems Biology (ISB) or data from their own aquaponic system to calculate water efficiency and the effects of scaling up a system. With or without the lab, students will explore what it takes to grow food by maintaining a stable system that mimics the resiliency of natural ecosystems. Using models to upscale these systems allows students to explore ways to reduce dependence on imports and water resources while still feeding a large population.

OBJECTIVES

What students learn

Students review the nitrogen cycle and how it can be engineered into a resilient system for growing food. This gives students context for better understanding the resilience of natural ecosystems and the importance of system stability. Students learn modeling can help inform solutions for global food insecurity.

What students do

Students apply systems biology approaches to illustrate an aquaponic network and then design a model system. Students scale up an aquaponic system to apply to a food system with limited water resources. Students analyze data from ISB systems and/or their own model systems to build and carry out an investigation.

STANDARDS

NGSS HS-ETS1-4 Engineering Design: Use a computer simulation* to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

DCI: ETS1.B: Developing Possible Solutions
SEP: Using Mathematics and Computational Thinking
CC: Systems and System Models

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

DCI: ESS3.C: Human Impacts on Earth Systems, ETS1.B: Developing Possible Solutions
SEP: Constructing Explanations and Designing Solutions
CC: Stability and Change

NGSS HS-LS2-7 (or HS LS1-3) Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

DCI: LS2.C: Ecosystem Dynamics, Functioning, and Resilience, LS4.D: Biodiversity and Humans, ETS1.B: Developing Possible Solutions
SEP: Constructing Explanations and Designing Solutions
CC: Stability and Change

NGSS HS-LS2-4 and NGSS HS-LS2-5** (standards can be applied).

Common Core State Standards Connections Mathematics -

Analyze proportional relationships and use them to solve real-world and mathematical problems. For HIgh School this standard is met through application of scale and proportion to work with this more advanced model. (CCSS.MATH.CONTENT.7.RP.A.3)MP.2 Reason abstractly and quantitatively, MP.4 Model with mathematics.

*(*This lesson aligns with the SEP and CCC within ETS1.B, but does not address this evidence statement. NGSS allows and values covering DCI, SEP, CCC's even without addressing a specific evidence statement. **See EXTENSIONS for more ideas that meet* **NGSS HS-LS2-4** *and* **NGSS HS-LS2-5** *STEM standards)*

Systems Education Experiences
Baliga Lab at Institute for Systems Biology

TIME 2 x 50 min (design/calculation for upscale)
Optional LAB: ~2 x 50 min. (dependent on system design) w/ weekly 20 min data collection/monitoring

PREREQUISITES
Students know the resources used to grow plants come from earth and its atmosphere. And have a basic knowledge of photosynthesis, nutrient cycles, and the process for plant growth. They will need middle school math skills in: percentages, ratios and proportion (CCSS.MATH.CONTENT.7.RP.A.3). Students have knowledge of creating systems network diagrams (Refer them to **Lesson 4** to re-familiarize with systems thinking).

BEFORE CLASS *

Display on computer:
- Food Security Vocabulary PowerPoint
- IRRIGATED CROP INFOGRAPHIC

Print 1 per student:
- So what is Aquaponics really? (science)
- Developing your Aquaponic System Plan (engineering)

Print 1 per group of 2:
- Network node cutouts
- Provide 11 x 17 paper, scissors, glue stick and markers.
- Or use: the *computer-based modeling system "Cytoscape"*

Upscaling calculations:
Teacher Read:
- **Teacher: Calculating Aquaponics efficiency and upscaling worksheet**

Print 1 per student:
- **Student: Calculating Aquaponics efficiency and upscaling* worksheet**

Print 1 per country group of 2-4:
- ISB Aquaponics Data (2017)
- **FAO AQUASTAT data sheets for Namibia, Haiti, DPR Korea: Water use summary and Vegetable production&Import data** or (pdf summary)

Display on computer/provide access:
- Abstract and Fig 3, p. 1588 in "The green, blue, and grey water footprint of crops and derived crop products", M.M. McKennon & Hoekstra, et al. (2011)
- **"Water Footprint of Food product gallery"**
- Field-to-Table school field program (www.wfp.org)
- **USDA food calorie calculator** (optional)

TEACHER INSTRUCTIONS
1. Classes learn by doing this system upscaling activity, even without building and investigating a model system in the "optional lab" (below). The activity is intended to inform student decision making in the Food Security Module Final Assessment: UN Summit Final Project. First So what is Aquaponics really? reviews the science behind these systems. Developing your Aquaponic System Plan guides them through the design/engineering process, but can be tailored to suit the time available. Then **Calculating Aquaponics efficiency and upscaling***using ISB Aquaponics Data (2017) , from a working model, applies engineered systems to a larger scale. Students evaluate the engineered systems as part of a global solution to Food Security as participants in the UN Summit.
2. **Warmup:** Use Food Security Vocabulary PowerPoint. (No. 7 "Calculating an Efficient system) Students define photosynthesis and nitrification. They will be reminded that growing food and traditional farming rely on balance in these essential cycles of ecosystems.
3. Next, students engage in **Defining the Problem:** Ask them: what if these food growing systems become out of balance? (Begin with Pair share and chalk-talk). How do we grow enough crops in a climate that does not produce adequate annual rainfall? What solutions are there? Gather ideas, then choose Irrigation to focus on. (eg. Importing vegetables, is a solution, but is costly). Can we reduce costs?

Display:IRRIGATED CROP INFOGRAPHIC. Irrigation uses a tremendous amount of resources for countries. Hand out So what is Aquaponics really? Students use the infographic to answer questions 1-6.

4. Remind them of examining farming methods in **Lesson FS2**. What food growing systems could help reduce the impact of drought? Review the science behind aquaponic systems by completing So what is Aquaponics really? questions 7-10. Aquaponic systems are known to use less water, land and fertilizers, but how?
5. Hand out network nodes cutouts, 11 x 17 paper, and markers to groups of 2. To help students see how these engineered systems compare to more traditional irrigation- and fertilizer-dependent farming methods, ask them to build a systems network diagram. *(See network diagrams student examples.)* Students draw arrows and label inputs and outputs to trace the water, nitrogen and carbon cycles that show ecosystems and nutrient cycles are central to the aquaponic system. How does energy that is input transfer through the system to become energy in the food that grows? *(See Extensions to meet* **NGSS HS-LS2-5 and NGSS HS-LS2-4:** *Nutrients, especially nitrogen, are part of the essential cycles for plant growth. The fish provide the fertilizer that in soil-based methods would have to be purchased and added. Photosynthesis inputs energy, carbon, oxygen and hydrogen to build cells, while nitrogen is for building DNA. Water cycles in the system bring nitrogen from the bacterial producers reducing any need for fertilizers).*
6. Ask students to think: "How could this engineered system that mimics a natural ecosystem be applied to the food system in a country? " (Reminder: systems can be built at different scales). First let us **Gather Information**: (pair share and write ideas on the board). Discuss, then write a testable question using an aquaponic system model as a solution for reducing water use. Prompt ideas: To test aquaponics what do we need to measure to show this is an effective change to a food growing system? (Example question : *How could we design a system to grow a crop that reduces [how much] water and produces [what amount] of this vegetable to reduce "imports" of this vegetable for the school for [a month]?*)
7. Hand out "Developing your Aquaponic System Plan" to guide students in using the planning processes engineers use to develop the aquaponic system. To save time, address only questions 1-4 (Include Steps 5-8 to fully meet the standard: **NGSS HS-ETS1-4 or HS-LS1-3)**
    - Ask: "What is the investigation goal?"
    - **Define the Problem:** *(The testable question they wrote).*
    - **Gather Information** *How is energy transferred and how are chemical elements exchanged in the model to produce plants? What variables do we measure to a) keep the system balanced and b) compare the outcome?*
    - **Draw a Diagram of the solution:** *Draw an aquaponic model and label each part with its role and show the cycles. How many plants will be grown? How many fish used? Pair-share designs.*
    - **Formative assessment:** *Compare system network diagrams to the the model plans. Have they described the nitrogen cycle, energy transfers and source, carbon cycle and the water cycle?*
    - **Make a prediction** *What is the expected outcome? (Ratio of plant growth to water use).*
    - **Test a Solution?** *What is measured to see the outcome? (water used and grams of crop produced).*
    - *Ask: "Could we produce enough of a single vegetable for the population of a country for one year? Could we apply these systems to use as part of a larger food production system?"*
8. Upscale these model aquaponic systems to answer these questions. Calculate how much the water footprint of lettuce is reduced if using aquaponics. Compare this evidence to the amount of water used for agriculture by the country already, to make a judgement. Could this reduce the cost each year on importing vegetables and make the food more available?
9. In their notebooks, ask them to do a rough estimate: What is the average daily vegetable requirement per person? Then show the Field-to-Table school field program (www.wfp.org). Announce that they will use

this 30 gram/per day estimate for their calculations. (For more student engagement use **USDA food calorie calculator** (optional) to help them estimate the calories provided for dietary requirements).

10. How many times will we need to harvest in a year to feed a country 30 grams per day? After some time to think how to calculate this, call on students to explain. Confirm: *For now, plan to upscale the systems to produce enough yield every 30-40 days (all year) to feed 30 grams a day per person.*
11. Now analytically **Test A Solution,** using data from the working model aquaponic system. Assign students to country groups of 2-4. Hand out results from the ISB aquaponic system model**:** ISB Aquaponics Data (2017). Point out the total water used and plants (lettuce) produced in a month is totalled in the sidebar. Note the size of the system and how many plants were harvested (Design Specification: 4 x 4 meter system, etc.). Ask How often was the water quality monitored? Why? (*Tell them food is measured in kilograms of the edible part. Energy (or kilocalories) could be measured using the dry mass of the plants.)*
12. Handout copies of the abstract and Fig 3, p. 1588 in "The green, blue, and grey water footprint of crops and derived crop products", M.M. McKennon & Hoekstra, et al. (2011) or see **http://waterfootprint.org/en/resources/interactive-tools/product-gallery/**. How did the scientists calculate the amount of water used to grow these foods (*Note: using traditional farming methods)*. Ask if they could reduce water usage using aquaponic systems to grow vegetable crops? Think and write a plan to calculate water use in science journals: "If we need 30 grams/per person per day per year of lettuce--how much water is saved if using aquaponic systems?" Which vegetables can be produced this way? How could they calculate the water used?
13. Here is a guide to help with the upscaling these systems. Hand out: **Calculating Aquaponics efficiency and upscaling*** (*Students can work independently to make calculations or use this guided worksheet).* What is the water footprint of lettuce when using aquaponics? Is it greater or less than the M.M. McKennon & Hoekstra, et al. (2011) calculation for lettuce at 237 liters/ kg.? Estimate the number of aquaponic systems and amount of water needed to supply lettuce crops for 100 student lunches in school.
14. Estimate the impact on water conservation for a country by answering questions in "Building Your Case." Upscale the system model to determine how many more should be built to supply the country with 30 grams per day of a vegetable? Hand out country water use Food & Agriculture Organization (FAO) **FAO AQUASTAT data sheets Namibia, Haiti, DPR Korea: Water use summary and Vegetable production &Import data** or (pdf_summary). If we grow lettuce using these systems, how much will it lower the amount of water used for agriculture and reduce vegetables to be imported for the country? Compare the results to the statistical water use in their country. What percent will be conserved? Why is there a difference? *(in traditional farming "hidden" water use derives from processing, evaporation, and soil absorption. Aquaponic systems could also reduce transportation cost and fertilizer use.)*
15. **Record the results of these calculations in the "Building Your Case" for use later in the FS 7 Module Final Assessment: UN Summit. In the UN Summit students will develop solutions and request aid from the United Nations to help improve food security in their country.* ***(see Lesson FS7: Part II-- Testing a Solution.)*** *Exit activity:* Based on your calculations for the ISB model aquaponic system, would it have a positive or negative impact on water use? (thumbs up, down) How does system's design play a role in the amount of water used? Ask them for ideas: Describe how aquaponic systems could be designed to fit into a country-wide food growing system.
16. Exit TIcket: Use Food Security Vocabulary Powerpoint.

ACCOMMODATIONS

- The optional lab (below) provides hands-on, small-group work— an important learning option for students with non-traditional learning styles. The visual learning from collecting data can be beneficial all students.

- For lower grade levels and differentiation: use data from ISB system and the step-by-step guided worksheet

EXTENSIONS

- If choosing the Optional Lab (below), students gain deeper understanding of system design when they compare the ISB model aquaponic system to data from their own models.
- Provide aquaponics node images but cover up the names of the nodes and edges. Students draw and label the systems network diagram using information they learned in **Lesson 2**.
- APES extensions: Calculating Population trends and impact of AQX system; or have students project the predicted population in 10 years. What will be needed to feed a growing population? How many more aquaponic systems should be planned?
- To challenge students to do more of their own thinking, investigate other questions (about fertilizers, crop production, etc.) using the UN FAO AQUASTATS database.
- Read a summary article for the country to gain deeper understanding of how aquaponics could affect the food growing system (eg. Haiti Briefing, UN 10 mil face food insecurity in North Korea, WFP Namibia brief)

RESOURCES FOR ACTIVITY:

- Food Security Vocabulary PowerPoint
- **Student worksheet:** So what is Aquaponics really?
- **Teacher worksheet:** So what is Aquaponics really?
- Network Nodes Cutouts (8.5 x 11 pdf)
- IRRIGATED CROP INFOGRAPHIC .**FAO. 2016. *AQUASTAT website*. Food and Agriculture Organization of the United Nations (FAO). Website accessed on [2017/10/03].**
- **Student worksheet:** Developing your Aquaponic System Plan
- **Teacher worksheet:** Developing your Aquaponic System plan
- **Student Worksheet:Calculating Aquaponics efficiency and upscaling***
- **Teacher Worksheet: Calculating Aquaponics efficiency and upscaling**
- ISB Aquaponics Data (2017)
- **Student worksheet:** Formative assessment
- https://www.wfp.org/stories/field-table-follow-food-home-grown-school-feeding-10-steps-haiti
- "The green, blue, and grey water footprint of crops and derived crop products", M.M. McKennon & Hoekstra, et al. (2011) or **http://waterfootprint.org/en/resources/interactive-tools/product-gallery/**
- **UN FAO AQUASTAT data sheets Namibia, Haiti, DPR Korea: Water use and Vegetable production_Imports data** or (pdf_summary)
- **Teacher data summary and FAO country overviews** (supplemental resources)**: Haiti, Namibia, DPR_Korea**.
- **USDA food calorie calculator** (optional)

RESOURCES FOR OPTIONAL LAB:

For more information about building in-class aquaponic systems below* and how to start your own Bacteria-rich water **Start Fishless Cycling aquaponics.**Teachers can research the system that suits their class size and needs, and start the bacteria fishless cycling 3-4 weeks prior to the scheduled lab. Once student's system designs from the activity (above) are approved, build the model aquaponic systems for lab investigations. Systems thinking is promoted as variables of the system influence growth of the plants. Choices here are limited only by the available tools to measure changes. Summative assessments let students compare their systems to the ISB system model.

LAB RESOURCES:

- Preview: Project Feed 1010 website for tips

- Read more about potential inhibitors to bacterial growth and the nitrogen cycle: Nitrifying bacteria facts (used with permission)
- **"How to Maintain a System/Become a Citizen scientist" PowerPoint**
- **LAB Student Guide** Building and Investigating a System
- **LAB Teacher Guide** Building and Investigating a System
- Formative assessment (weekly), see EXTENSION ideas (below)
- Water quality testing and maintaining a system (test strip version)(based on API Water quality testing kits)
- **Data collection tools:** *(See "ISB Teacher Helpful Guide" of best practices)*
  - Option 1: API liquid chemical test kits (see aquarium stores)(Note: test strips less reliable)
  - Option 2: Vernier or Neulog probes/groups of 8-12 students: sets of NH4, Nitrate, DO, pH, Temp

OPTIONS for AQUAPONIC SYSTEM DESIGNS and SET UP INSTRUCTIONS

Resources: *crowd-source funding, teacher feedback, and how to choose the right system for you*

	Build cost ($-$$$)/ classroom build time			
	$ / <1-hour	**$ / <2-hour**	**$$$ / <5-hour**	**$$ /<1-hour**
Option #	**1**	**2**	**3**	**4**
***System Designs**	**Hydroponics Mini-Challenge**	• **2-Liter Bottle student systems** • Materials **&** "Fishless" data sheet • **Air-lift pump or wick?**	**Large scale systems 2' x 4' OR 4' x 4': https://see.systemsbiology.net/projectfeed1010/**	**Prefabricated systems: Back to the Roots** or **AquaSprouts**
Description	Simple, space/time saving, invent your own systems. Uses recycled micropipette tip boxes. For classes of 22-35 students in teams of 2-4 or individually.	Bench or countertop systems with simulated or real fish. Student-built and operated for 22-35 students in teams of 2-4. Gives a real sense of water use to produce a vegetable crop Student example. High level of individual engineering.	Class design and modify. Small group of students help build. Best for small classes or clubs. Rotate teams to collect daily/weekly data and make observations.	Online purchase demonstration models—easy set up on a countertop. Best for small classes. Rotate 2-3 students to collect data and make observations.

*In each case, students measure plant growth, nitrite, nitrate, dissolved oxygen, pH, and ammonia levels in their systems and record data on ISB's online data management hub (https://pf1010.systemsbiology.net/). The student-designed systems will vary in productivity. *No matter which option is used, the process will help students learn as they collect water chemistry, water use, and plant growth data over 4-5 weeks (or longer if desired).*

EXTENSIONS/ENRICHMENT

- To meet **NGSS HS-LS2-5:** Use the aquaponics system to model the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. Identify these on the aquaponic system network diagram and connect each to nodes in the carbon and water cycle. How would a shortage of water (or other variable) change increase/decrease the processes of photosynthesis and cellular respiration?

- To meet **NGSS HS-LS2-4:** Show biochemical exchanges and energy transfers found between the nodes of the aquaponic system network diagram. Test water quality with a focus on the chemical changes. Record evidence of trophic level energy exchanges [where is the energy input coming from?].
- **Engineering practices:** Use a Formative Assessment to compare their model system with other model systems weekly. Compare within the class or upload data to the PF1010 data management hub (pf1010.systemsbiology.net) to compare to other models in the country. Redesign the models and test by growing a new crop. Was the water use decreased? Did the plants grow more?
- **Energy transfer:** Food has calories (kilocalories) Where is the energy coming from to produce these calories? Calculate the calories produced in the system for each crop. **USDA food calorie calculator** (Further exploration: measure input from solar cells, estimate energy output for pumps, calories in fish food, etc)

FEEDBACK

- ➢ Link to survey on SEE website and contact information
- ➢ Link to PF1010 Website