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A Better Way of Farming

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A Better Way of Farming

Building an aquaponics system in the classroom

STEPHANIE RAINS AND BROOKE A. WHITWORTH

Alternative farming techniques are often more efficient and conserve resources more effectively than conventional farming, which can harm the environment with pesticides and synthetic fertilizers (Pimental 2005). To learn the theory, application, and related science concepts of sustainable farming techniques, students can collaborate to create an alternative farming system in the classroom.

This article describes a unit on *aquaponics*, a soilless method of farming that blends aquaculture and hydroponics. A symbiotic relationship forms between fish and plants to create a healthy system for farming with minimal water usage through a recirculation system. A simple aquaponics system consists of a fish tank with live fish beneath a plant grow bed (Figure 1). A small aquarium pump moves water from the fish tank up to the plant grow bed, and then gravity returns it to the fish tank, making a continuous cycle.

Bacteria in the grow bed convert ammonia from fish urine in the water to nitrites. Plants absorb the nitrites for growth, and in turn detoxify and oxygenate the water, keeping the water healthy for the fish (Figure 2, p. 42). Students work through the engineering design process; support and argue from evidence; develop sustainable, alternative methods for farming; and take part in creating an ecosystem. The unit aligns with the *Next Generation Science Standards* (NGSS Lead States 2013; see p. 45).

We developed this lesson for ninth-grade biology students to be completed in 10 80-minute classes, but it can be adapted to any grade level and class schedule. Students should already be familiar with the nitrogen cycle, photosynthesis, and how plants obtain nutrients. A goal is for students to research, prototype, test, construct, evaluate, and revise their engineering designs through multiple iterations. Engineering practices are embedded in the content to support students' understanding of key concepts.

Starting the unit

The unit begins with a class discussion of farming, farming methods, and the effects farming has on the environment. Students then discuss their concepts of alternative farming and how it might affect the environment differently. We then talk about the importance of plants, what plants need to thrive, and how they benefit our world.

Next, we divide students into groups of three or four students and create diagrams of how the photosynthesis and nitrogen cycles work. Students should be able to describe the cycles easily, but if not, this activity helps clarify the concepts. Teachers should facilitate and guide this process by asking guiding questions and encouraging students to question one another.

Each group should keep a design log (see "On the web") to express thoughts and ideas and to make their thinking visible. The teacher should clearly explain expectations for completing the log and may decide to allow students to design their own.

Because this is an engineering design task involving teamwork and live animals, students need clear expectations of each other. Groups should assign roles (e.g., project manager, materials manager, safety and control manager, and recording and communications manager). Teachers can specify tasks and responsibilities for each role in a group contract signed by each team member (see "On the web"). Group and individual evaluation forms will be filled out at the end of the unit (see "On the web"). A group contract should minimally include:

- roles for each student,
- a plan of action if a team member fails to do his or her work, and
- a list of expectations.

Debate and research

Pairs of groups form to debate conventional and alternative farming methods and whether they are for or against that method. Students sign up for the farming method they would like to debate (e.g., conventional farming, crop rotation, planting cover crops, integrating pest management, aquaponics, agroforestry). Using the design logs to document their research and progress, students research their chosen farming method and argue their position, perhaps using the claim, evidence, and reasoning framework (Sampson, Enderle, and Grooms 2013).

FIGURE 1

Constructed aquaponics system.

To support a strong, evidence-based argument, groups also need to research the opposing side of the debate and plan questions to ask the other team. Students write a research paper as a group, detailing their arguments. The paper encourages evidence-based, open-minded discussion and documents each group's point of view while demonstrating that evidence and logical reasoning are important to defending a position on a topic. Each group is given a rubric to guide their work (see "On the web"). As an alternative, Knight and Grymonpre (2013) offer a different rubric that focuses on the strength of the argument.

Engineering design

The teacher reviews the concepts of aquaponics with the class and asks students to consider the materials available and what kind of aquaponics system they could make with the available materials. Each group member should express his or her thoughts about how to design an aquaponics system. Each group should draw the design of its system and list the needed materials in its logs.

Available resources and budgets determine how many systems may be built. Our initial 50-gallon systems cost roughly $70 with materials purchased at pet stores, grocery stores, and home improvement stores. Systems may be cheaper depending on which tanks, fish, water pumps, and grow media are selected. As a class, we built two large aquaponics systems.

Ideally, every student should participate in construction. If materials allow, each group may build a smaller, individual system. Or, two groups may be combined for the construction, with appropriate adjustments made to the group contract.

Fish and plants

Students should research, adding notes to their logs, which type of fish would be best for this system. Guiding questions might include:

- What is the behavior of the fish species?
- What does it need to survive?
- Does it get along with other fish?
- Is it a cost-efficient fish?
- How long does it take to become fully grown?

Students need to do the same research for determining the best plants for the system. Guiding questions might include:

- What needs does this plant have?
- How well does it grow?
- Why do you think it is the best choice?

After the research is concluded, each group presents evidence about which fish and plants are best for the aquaponics system. Then, students vote as a class on which fish and plants they would like to use.

Plant-to-fish ratios are an important consideration in designing the system. A system with too few plants and too many large fish won't provide enough clean water for the fish to survive. Leafy lettuces, peppers, and kale have been the best plants for the aquaponics system, though any plant may be used. Students typically find that tilapia is a good choice due to faster maturity rates and ease of maintenance. Tilapia can tolerate crowding and fluctuating water conditions, but you might need permission to culture this exotic, non-native species from your state's fish and wildlife agency. Fish and fish food can be purchased at a pet store or tilapia farm (see "On the web").

Teachers should note that adding nitrifying bacteria (available at pet stores) before the fish are placed in the water will promote the bacterial colonization needed for this experiment almost immediately. It could otherwise take months as fish start cycling ammonia through the system.

System construction

Before construction, teachers should remind students of appropriate behavior while building the aquaponics systems (Figure 3). The project involves sharp tools, live fish, and live plants, each of which needs explicit cautions. Students should be reminded of their designated roles listed on their signed group contracts.

Students should follow the designs they entered into their design logs. If they alter the design, such as not having the plants above the fish, revisions should be entered into the logs in a different color ink.

Encourage students to follow their own design but to keep certain factors in mind. The most efficient system places the grow bed above the fish tank, allowing for water to flow freely from the grow bed back into the fish tank, requiring only one pump. A bell siphon could be used in the grow bed for the water

FIGURE 2

The aquaponics cycle.

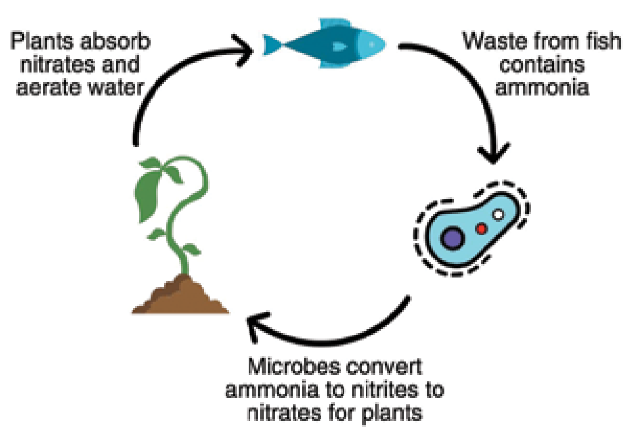
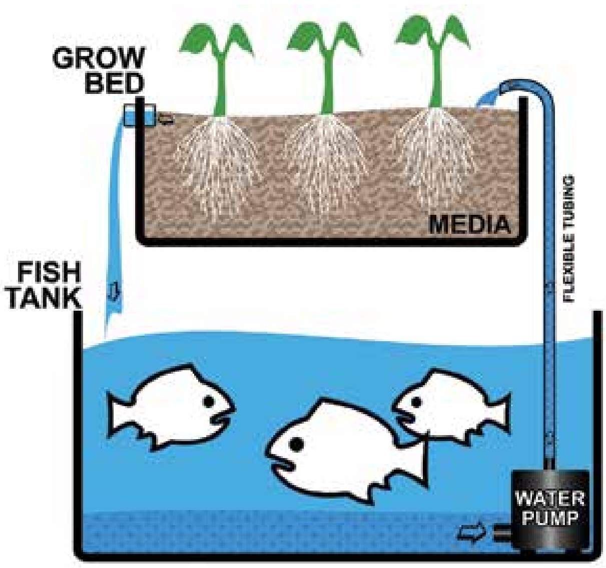


FIGURE 3

Aquaponics diagram.



Materials

Basic aquaponic materials that each group will need. Some items added for variety:

1. 27–75 liter (7–20 gallon) clear plastic tote boxes
2. Hydroton for media
3. Water pump
4. Plastic tubing to fit water pump
5. Air pump and airstone
6. Grow bed
7. Plastic water bottles
8. Fish
9. Plants
10. Netted plots
11. Bell siphon

Extra materials teachers might need

1. Drill and drill bits
2. Hot glue gun
3. PVC pipes
4. Electrical tape
5. Extra tubing
6. Mesh filtration floss

return, but it requires more materials and has been found difficult to keep clean from algae build-up.

Many aquaponics systems need to maintain a steady pH level. Fish and bacteria prefer a slightly alkaline environment, while plants prefer a more acidic one. Generally, the perfect pH for these systems is 6.0–7.0 (Somerville et al. 2014). Students may use pH strips to collect and record data either daily or every other day. If pH levels are too high or too low, students will need to find a solution to steadily increase or decrease pH.

The most effective way to stabilize pH is through changing water. Students may use a gravel vacuum to empty the water and refill the tank with fresh water. Since students will be building a small system, pH can stabilize on its own and this part of the lesson may not be necessary. However, it is useful for practicing data collection and pH monitoring.

Farming methods evaluation

The goal is for students to discuss and determine the effectiveness and efficiency of an aquaponics system. Guiding questions could include:

- Is this method better than conventional farming?
- How does it compare to other alternative farming methods?
- How cost-effective is it?
- Is it reliable?

Relating aquaponics systems to real-world problems highlights how other farming methods may damage the environment.

To incorporate mathematical modeling into the project, students might simply calculate the ratio of plants to fish. For a more challenging task, they can calculate the efficiency of the system, using four possible methods (Figure 4) as an extension to the unit.

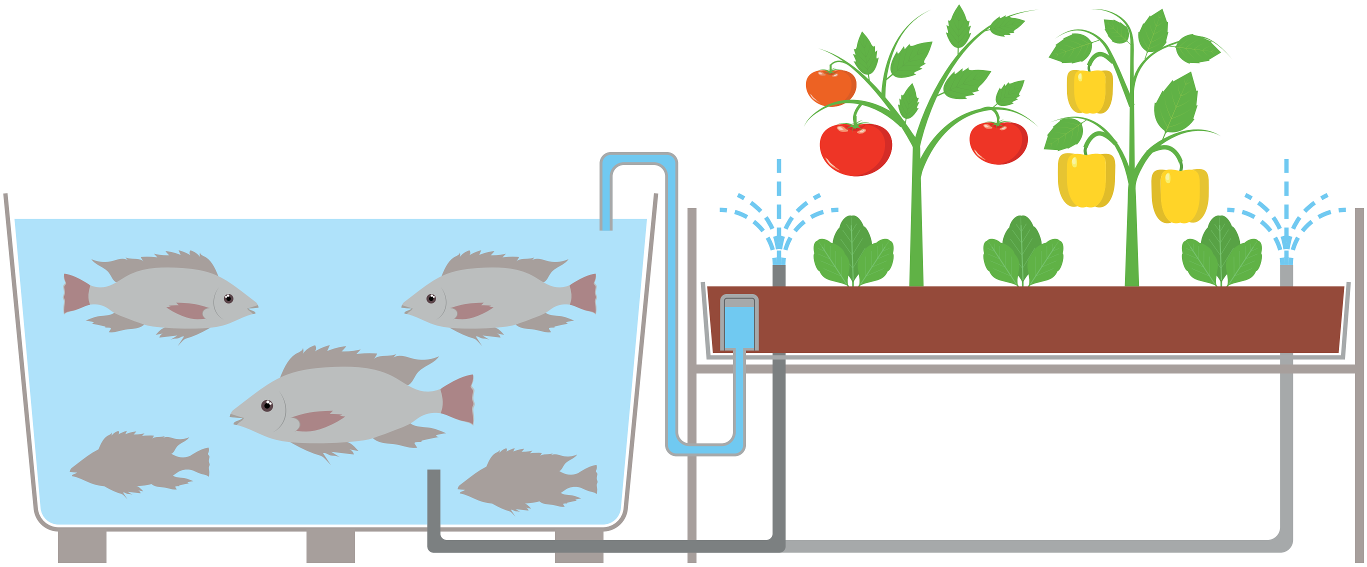
For example, if a group believes the number of plants grown directly relates to the amount of food given to the fish, students should be able to explain that they think the more fish

FIGURE 4

Calculating system efficiency.

Below are four approaches that students might use to calculate the efficiency of an aquaponics system.

1. Volume of water in fish component : Volume of water in plant component
2. Volume of water in fish component : Volume of media in growth bed
3. Number of fish : Volume of media
4. Number of plants that are grown: Amount of fish feed that enters system



eat, the more waste is produced, thus, the more nitrates the plants absorb, the more plants grow. Typically, the ideal ratio for the classroom system is 60 grams of food/m^2/day (Lennard 2012). Students should also connect their ideas of how the system works to the nitrogen cycle and to photosynthesis.

Redesign reflection

After groups have constructed their aquaponics system, they should reflect on how they would redesign the system to make it more effective. Iteration is a central aspect of engineering, and even if students do not actually complete the redesign, considering changes is important (Whitworth and Wheeler 2017). If time and materials allow, students may reassess, redesign, modify their aquaponics system, and retest the new design.

Assessment

For formative assessment throughout the unit, the teacher regularly or sporadically checks students' design logs to keep students on track and address problems that may arise. For summative assessments, the teacher grades the debate, research paper, and final version of the design log (see "On the web"), also awarding points for evidence of effort and group and individual evaluations according to the rubric (see "On the web").

Conclusion

An aquaponics system is an excellent demonstration of how nitrogen cycles through an ecosystem. Designing and building a functioning aquaponics system not only imparts core science and engineering ideas but also helps students understand how alternative farming methods can make farming more sustainable and less damaging to the environment. ■

ON THE WEB

Aquaponics cycle diagram: *http://smallgarden-ideas.com/aquaponics-systems*
Backyard Aquaponics: *www.backyardaquaponics.com/guide-to-aquaponics/fish*
Design log template, group contract, group and individual evaluation, grading rubric: *www.nsta.org/highschool/connections.aspx*
Southwest Tilapia Farm: *http://southwesttilapiafarm.com*

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standards

HS-LS2: Ecosystems: Interactions, Energy, and Dynamics

HS-ESS3: Earth and Human Activity

Performance Expectations

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions

HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.

HS-ESS3-1. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Constructing Explanations and Designing Solutions Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources	Students create models to explain from observation how matter cycles in ecosystems and why it will continue to cycle.
Engaging in Argument from Evidence Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments	Students research and defend a comparison of cost-effectiveness, social and economic impact, safety, reliability, and aesthetics in both alternative and conventional farming.
Using Mathematics and Computational Thinking Use mathematical representations of phenomena or design solutions to support claims.	Students use mathematical equations to determine proper aquaponics efficiency and regulation.
Disciplinary Core Ideas	
LS2.B: Cycles of Matter and Energy Transfer in Ecosystems Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.	Students use their understanding of photosynthesis and matter cycling to design their aquaponics systems.
ESS3.A: Natural Resources 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.	Students compare social and economic cost-effectiveness of aquaponics system versus other agricultural methods (hydroponics, normal agriculture, etc.).
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. (secondary)	Students should think about available materials, the type of fish and plants being used, how safe and reliable it will be, and the impact it has on the environment and culture.
Crosscutting Concept	
Energy and Matter Energy drives the cycling of matter within and between systems	Students model how matter cycles.