AC 2009-2482: A BRINE-SHRIMP ECOSYSTEM DESIGN PROJECT FOR 5TH- AND 6TH-GRADE STUDENTS

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Abstract

As engineering strives to increase its student numbers, more and more programs in biological engineering and other areas are developing outreach efforts for K-12 students. An important component of this type of outreach is the creation of grade appropriate design experiences. This project has developed a hands-on curricular module to examine the role of various components of a brine shrimp (Artemia) ecosystem in a classroom setting for fifth and sixth grade students. An understanding of these various components is formed using an ecological engineering design project. In the curriculum, the students are asked to design an ecosystem capable of supporting brine shrimp. The module was developed to be a 45-minute hands-on capstone activity with an emphasis on analysis-based design. It was designed for a school visitation program that reaches approximately twenty thousand fifth and sixth grade students annually. It includes teacher support materials such as activity descriptions and equipment requirements. In addition, it details the student and material implementation cost. This project fulfills several requirements from the *Standards for Technological Literacy* and the *National Science Education Standards* for the fifth and sixth grades. Therefore, creation and dissemination of this project has the potential for outreach and wide use in the classroom.

Purpose

Currently, China is producing more graduates in engineering than the US. According to a recent study in 2004, China had 664,106 graduates compared to the US' 222,335 [1]. In addition, the number of foreign nationals obtaining higher education degrees in the US is rising. Engineering literature is coming to the consensus that the decision to enter engineering occurs during high school or early college, while the decision *not* to enter engineering occurs in the sixth to eighth grades. Without effective outreach at this early level, the US will fall behind other developed countries such as China and possibly India [2-5].

The lack of effective outreach combined with the public's limited perception of technology as being only "computers and matters related to the internet" [6] means that students will not be introduced to engineering and design at an early enough age. Pre-engineering is not a subject on its own in public schools; however science, technology, and pre-engineering go hand-in-hand [7]. Therefore, engineers must place outreach programs in existing subjects such as science and technology.

This means it is necessary to help science and technology teachers understand the importance of pre-engineering in education, and that they must incorporate more pre-engineering design into the standard K-12 curriculum. This module incorporates science, technology, and design in a project for fifth and sixth grade students. With this blend, fifth and sixth grade students will experience elements of design which is a fundamental part of pre-engineering education. When students gain this understanding of design and its relation to engineering, substantial engineering outreach will be achieved.

Standards Addressed

Pre-engineering and design primarily enter the K-12 curriculum through science or technology education. These subjects are guided and directed by national standards known as the *Standards for Technological Literacy* (STL) [8] and the *National Science Education Standards* (NSES) [9]. It is essential for this project to address these standards in order to achieve wide adoption. Otherwise teachers cannot justify the use of this project in the face of an already full curriculum and regulations like the *No Child Left Behind Act.* This module blends three standards from the STL and two standards from the NSES.

The STL standards addressed in this project are:

- *Standard 2: Students will develop an understanding of the core concepts of technology,*
- *Standard 8: Students will develop an understanding of the attributes of design,*
- *Standard 15: Students will develop an understanding of and be able to select and use agricultural and related biotechnologies.*

STL *Standard 2* helps students learn about resources such as materials and energy, think in terms of systems and interactions within those systems, develop the concept of trade-off in the design process, and understand the need for system maintenance. STL *Standard 8* helps students learn that the design process is a creative planning process; there is no perfect design, and requirements for design are made up of criteria and constraints. STL *Standard 15* helps students understand that artificial ecosystems are human-made environments; they are designed as a functional unit, and most agricultural waste can be recycled.

The NSES standards to be addressed include:

- *Standard C: Students will develop an understanding of: structure and function in living systems, reproduction and heredity, regulation and behavior, populations and ecosystems, and diversity and adaptations of organisms,*
- *Standard E: All students should develop: abilities of technological design and understandings about science.*

NSES *Standard C* helps students progress from studying life science concerning one individual organism to recognizing patterns in entire ecosystems. This also includes understanding how one species lives in its environment, population, and community of species. *Standard E* focuses on understanding the similarities, differences, and relationships between science and technology. This includes helping students realize that technological design and problem solving involve other factors besides scientific issues, such as design, implementation, and evaluation.

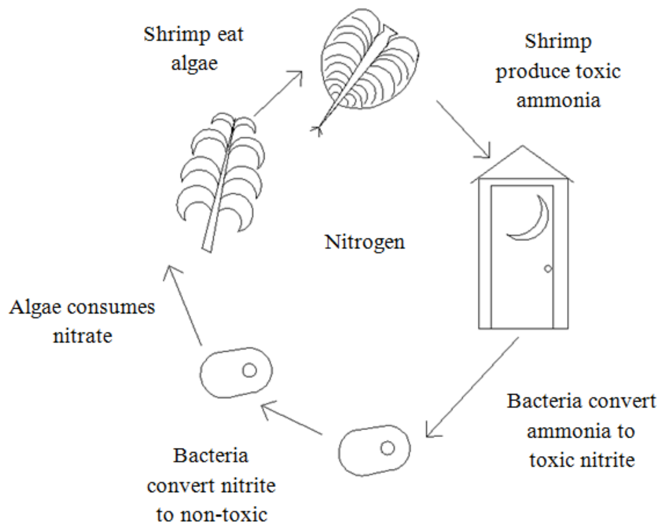
The Brine Shrimp Ecosystem

To facilitate the student's ability to understand the ecosystem and the problems involved, information about brine shrimp is provided. Brine shrimp (Artemia) are in the phylum Arthropoda and class Crustacea. They are closely related to shrimp and zooplankton and are commonly used as food for aquariums [10]. Nauplii hatch from dormant cysts and enter the first larval stage. Nauplii filter feed on various microalgae, bacteria, and detritus. A new nauplius is born with only three legs and gains a new pair during each of the first ten molts. They molt 15 times in 8 days before reaching adulthood. Adults average 8mm long in length and can live up to four months. They can eat various foods including yeast, rice bran, whey, wheat flour, soybean powder, fish meal, egg yolk, and homogenized liver. The males are distinguishable from the females because they have large claspers for their antennae while the females have a broad pouch at their posterior [11]. An adult female typically produces up to 300 nauplii or cysts every 4 days [12].

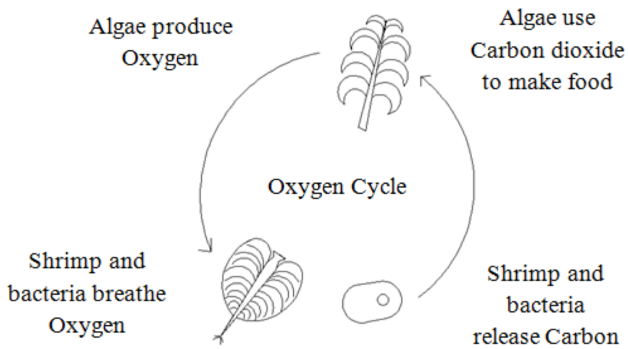
Cysts can move around through birds by passing through their digestive tracts unharmed. Brine shrimp typically live in harsh environments with no predators. These environments are found in the San Francisco Bay, the Great Salt Lake, Brazil, Spain, Australia, India, China, etc [13]. Artemia thrive in waters at a temperature of 6-37°C (43-95°F), a pH of 8-9, and an optimal salinity level of 30 ppt although they have been seen to grow at levels as high as 340 ppt [14]. At favorable oxygen conditions, they are pink, yellow, or green because they feed on microalgae. At less than optimal oxygen levels, they feed on bacteria, detritus, and yeast cells. They also produce hemoglobin which causes them to turn red or orange [12].

Simplified Ecosystem Cycles

One of the things students will learn is the nature of an ecosystem. Each member of the system depends on other members to survive. Two prime examples of this dependence are the nitrogen and oxygen cycles. During the nitrogen cycle, ammonia (NH_3) results when shrimp either produce waste or become waste by dying. Ammonia is toxic and, if not taken care of, it will poison the remaining shrimp. That is why the ecosystem needs bacteria. Bacteria will transform the ammonia into a less toxic compound called nitrite (NO_2^-) and then into a non-toxic compound called nitrate (NO_3^-). Algae plants consume the nitrate produced by the bacteria. Finally, the algae are consumed by the brine shrimp, thereby completing the cycle (see figure below) [15, 16].

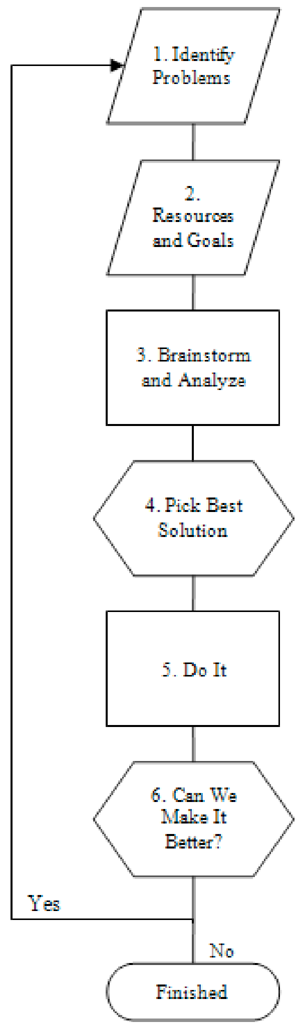


Another cycle the ecosystem depends on is the oxygen cycle. During the oxygen cycle, brine shrimp and bacteria take in oxygen (O_2) and release carbon dioxide (CO_2). Algae will use the carbon dioxide to produce sugar molecules to use for their food. The algae then produce oxygen which is used by the shrimp and bacteria (see figure below).



Design Process

A key characteristic of engineering is analysis-based design. This project uses a simplified design protocol, as shown below, designed for fifth and sixth grade students. This entire module fulfills STL *Standard 8* because it is a pre-engineering design project using the design process as a guide through the module [17].



1. *Identify Problems*

   Identifying problems is the first part of the design process and helps establish a purpose or need. Without this purpose or need, there is no reason for design. For this module, the purpose is to grow brine shrimp in the classroom. NSES *Standard C* is addressed by teaching students about brine shrimp ecosystems and their structures. This section also highlights STL *Standard 15* as students gain an understanding of how products are made by one organism and used by another. For example, bacteria convert brine shrimp waste into nitrates used for food by the algae that then go on to become food for the shrimp. The bacteria's conversion of the waste from toxic ammonia to nitrate not only provides food for the algae, but is also essential for the water quality of the ecosystem. Without the biofiltration provided by the bacteria, the ammonia would poison the brine shrimp.

2. *Goals and Resources*

   The goals, or requirements, for a design project are important because they indicate when the design is done. Identifying goals encompasses NSES *Standard E* because it helps students understand why the design process is used. Determining available resources addresses STL *Standard 15* because resources limit what can be used or designed in agriculture and biotechnology.

3. *Brainstorm and Analyze*

   Brainstorming and analyzing are unique aspects of the design process because they require the use of math, science, common sense, and creativity. Brainstorming helps generate ideas for solving the problem effectively. Analyzing helps to determine if the idea fulfills the goals of the design and uses the resources provided. This section fulfills STL *Standard 2* by helping students think in terms of the ecosystem, the design, and the concept of trade-off. Trade-off involves deciding which of the available resource should be utilized.

4. *Pick Best Solution*

   After coming up with a few designs, it is time to choose the best one. This choice can be made by considering the background information, goals, and available resources. STL *Standard 15* is employed by students designing a human-made, artificial ecosystem and learning how waste is controlled within the ecosystem. NSES *Standard C* is also covered because the students are looking at an entire community of brine shrimp and the part they play in their ecosystem.

5. *Do It*

   After deliberation comes implementation. This is the time to move the plan from paper to reality. If the design process had not been followed, likely the students would have started making ecosystems with little forethought or planning. This approach often wastes time and resources when it leads to ineffective, problematic solutions. This is why the first four steps of the design process should be followed before implementation. This step addresses NSES *Standard E* because the science background is used to design and build the ecosystem. STL *Standard 2* is also satisfied because in the building process, students will understand how every part relates to others within the system.

6. *Can We Make It Better?*

   Once the system has been built, the students refer back to the design goals. Were the goals successfully met? Is there a better way to build this system based on our resources? This step addresses NSES *Standard E* because the design process utilized math and science to expand students' understanding of the relationship between science and technology.

Conclusion

This module will achieve substantial pre-engineering outreach as it is used for fifth and sixth grade students. The project outlined is suitable for the standard K-12 curriculum and encompasses several national standards for science and technology as outlined above. To further student understanding, background has been provided about brine shrimp and cycles within the ecosystem. Students are exposed to pre-engineering and design while building a self-sustaining ecosystem. For additional resources, see appendix A and B which contain a suggested lesson outline and protocol.

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Appendix A

This appendix is provided to help teachers implement the design project in the classroom. Though the process as outlined in the paper is simplified for age appropriateness, the basis of the design process comes from methods used in the field of engineering today [17, 18].

The following is a lesson outline of the design process for this project:

1. *Identify Problems:*

   In all design there is always a need or goal. The purpose of this step is to understand the problem and, ultimately, what problem must be solved. For this project, the goal is to design a self-sustaining ecosystem using brine shrimp and algae. With this goal, other questions must be answered so as to understand *how* this goal can be achieved. The following are some example questions:

   - How do brine shrimp grow?
   - What kind of environment do they live in?
   - What do they eat?
   - What does their food need to survive?

   From this step, students should understand that, without a problem, there is no need for design. Furthermore, to achieve the goal, sometimes more knowledge about the problem is needed.

2. *Requirements and Resources:*

   This is a key step in the design process. It defines how a design will work and when the design will be considered adequate to achieve the goal or need from step one.

   Requirements define design criteria such as size, cost, and how long the product must function. In this step, students must use information gathered in step one to define the requirements. Possible requirements are as follows:

   - Brine shrimp need to survive
   - Algae need to grow
   - Ecosystem must be manageable in size

   Resources are what limit your design. They involve what is and is not available to use. Therefore, students must understand what is available and what resources might be used. Necessary resources include:

   - Brine shrimp cysts

- Clear plastic cups
- Treated water
- Testing materials

To incorporate more design rather than simple procedure, students must have *choices*. Additional materials should be used, so that students can choose what may or may not work. Materials including, but not limited to, the following suggestions may be used:

- Various sizes of containers (e.g. 2-liter pop bottles, plastic containers, etc.)
- Various items to put into the container to promote algae growth (e.g. sponges, pebbles, leaves, plastic plants, etc.)
- Other resources that may not be necessary (e.g. glue, toothpicks, markers, paper, scissors, etc.)

Students must understand that, in design, there are multiple ways to solve a problem. Requirements help determine when the design is done, and resources determine how the design will be created. When looking at requirements or resources, it is frequently easier to ask, "What can it not do?" and "What cannot be used?" Students' creativity should be encouraged in what they *could* use.

3. *Brainstorm and Analyze:*

In this step, possible designs are created to solve the problem. Students brainstorm ideas on how to set up a working ecosystem. During this process, remind the students of the background information from step one. Also, be sure they do not use something that is unavailable and that their design fits the requirements from step two. Have the students generate as many ideas as possible, however, a good number of designs is between three and five.

The following are possible designs for the students (see Appendix B for a standard design):

Design A – Set up an ecosystem solely with brine shrimp and algae in the cup

Design B – Explore putting different items, such as rocks, in the cups to promote

algae and bacterial growth

Design C – Explore the effects of lighting conditions upon the ecosystem

Here again, students are encouraged to be creative. There is no one design for this module, merely a *suggested* design. Students must understand that design invites creativity, but it is like a puzzle because of the requirements and resources.

4. *Pick the Best One:*

This step is critical in design because students analyze the generated designs to find the best or optimal design. Since true analysis of the designs may take much time and effort, students will need help to examine good designs, better designs, and possibly, the best design. This can be done by comparing the requirements and resources from step two with the proposed design alternatives. Ask questions such as:

- Does the design fulfill *all* the requirements?
- Does the design use the resources effectively?
- Is the design efficient?

Students must understand that analysis is where science, math, and common sense are applied. Students should ask themselves, "Does this design make sense? Can one prove that the design will work?" After answering these questions, the design that fits all the requirements, has good use of the resources, and makes sense should be the design used for step five.

5. *Do It:*

This is one of the most exciting steps in the design process because this is where the design goes from paper into action! Students will implement the design they have chosen and build the ecosystem. Once the ecosystems have been set, the students will observe them and take notes over the next two weeks (or a time period chosen by the teacher). The following questions can be answered during the observation period:

- Is the system functioning?
- Are the brine shrimp alive?
- Are the algae growing?

6. *Can We Make It Better:*

This is one of the defining steps in the design process. In the professional world, this step is used regularly. Design is about iterating until the most efficient, cost effective, optimal design is reached. Recall that in step three, multiple designs were generated; in step four, the best design was selected; and in step five, the design was implemented. This step looks back on the design and asks, "Can we make it better?" The notes taken during observation can be used to answer this question [11]. The students can discuss what they would change if they were to repeat the design process. Discussion topics include:

- How the ecosystem could be improved
- What worked and what did not

- What they would do differently

Students should understand that this process can be used as many times as needed until the best design is achieved. They must also understand that, by using this *design process,* they were able to come up with designs that will work and still be creative. Once the discussion has covered any and all observations, the students have successfully completed the design process.

*Note: This is a suggested outline. The teacher may, at anytime, add new ideas for possible designs, requirements, resources, or observation questions. However, the nature of the *design process* must be observed.

Protocol

Note: This protocol is designed for 15 ecosystems which will accommodate up to 45 students.

Equipment used:

- Algae water
- Brine shrimp cysts – $10 at aquarium or pet stores
- Salt for aquariums – $3 at aquarium or pet stores
- Water conditioner – $3 at aquarium or pet stores
- 1 teaspoon measurer – $1 at department stores
- 1.5 cup (12 oz.) ladle – $1 at department stores
- 2 gallon bucket – $2 at department stores
- 16 oz. translucent plastic cups – $2 at department stores
- Marker – $1 at department stores

Procedure followed:

1. At least two hours before the project begins, fill the 2 gallon bucket with tap water. Add water conditioner according to the package instructions. Then, add 6 tablespoons of aquarium salt to the water. Stir the water and allow it to reach room temperature.
2. Present the brine shrimp information, and have students start the design process (see Appendix A).
3. Divide the students into groups of three. Give each group a cup. Using a marker, have them label the cup with their group name.
4. Allow each group to add 1.5 cups (12 oz.) pre-treated water from the bucket. Have groups draw a line marking the water's surface on their cups.
5. Allow groups to add 1 teaspoon algae water to their cups.
6. Add a very tiny amount (less than 1/32 of a teaspoon) of brine shrimp cysts to the cups.
7. Place cups in a safe place with a light source (near a window for light if possible).
8. Rinse out bucket. *Do not use soap.* The container can be reused, if needed.
9. Check cups two to three days later. If the water level is lower than the line drawn by the students, add more conditioned water (the addition of salt is not necessary).