Supplemental Material

CBE—Life Sciences Education

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SUPPLEMENTAL MATERIALS

Supplemental Materials S1. In-class activity on nitrification in aquaria used in week 1 to introduce SMRF modeling.

"New Tank Syndrome" and how to avoid it.

Introduction: You buy your very first brand new fish tank for your room, you populate it with beautiful, expensive fish, you feed them right and often, but they soon become sick and die within a couple of months. What happened? Your fish were poisoned by their own biological wastes, a common event known as "New Tank Syndrome". An expert would tell you that you need to "cycle" or "mature" your tank, which in biological terms means that you should allow a process called nitrification to happen.

Nitrogen (N) is the fourth most abundant element in living things, being a major constituent of proteins, DNA and RNA. Like all living creatures, fish eliminate nitrogen through their waste products. Much of this nitrogen is in the form of ammonia (NH_3), which is highly toxic to fish. In oceans and lakes, ammonia is diluted to such low concentrations that fish are unharmed by it. In aquaria, however, the volume of water is much smaller and ammonia builds up to toxic levels very quickly.

Nitrification is a biological process that converts ammonia into a non-toxic nitrogen compound, nitrate (NO_3^-). Two different types of bacteria carry out this process. *Nitrosomonas* bacteria consume ammonia and convert it to nitrite (NO_2^-), while *Nitrobacter* bacteria consume nitrite and convert it to nitrate (NO_3^-). These species of bacteria are present everywhere in the environment and they will multiply and colonize a new tank if their source of nitrogen is present and abundant. Therefore, once you have ammonia- producing fish in your tank, within a few days *Nitrosomonas* multiply and establish a colony in your filter bed. The most common way to do this is to place only one or two fish in your new aquarium: they will begin producing the ammonia *Nitrosomonas* use to grow. Nitrate- forming bacteria (*Nitrobacter*) will not begin multiplying until there is plenty of nitrite in the water. When both types of bacteria have colonized the aquarium, ammonia levels will be
low to zero, nitrite levels will be low, and nitrate levels rise. Plants, including aquatic plants, directly use nitrate for their growth. Your tank is fully cycled!

Sources:
http://www.cs.duke.edu/~narten/faq/cycling.html
http://www.fishkeeping.co.uk/modules/newbb/viewtopic.php?post_id=4954 Raven, Biology 9 Ed., McGraw-Hill (Keywords: nitrogen cycle; nitrification)

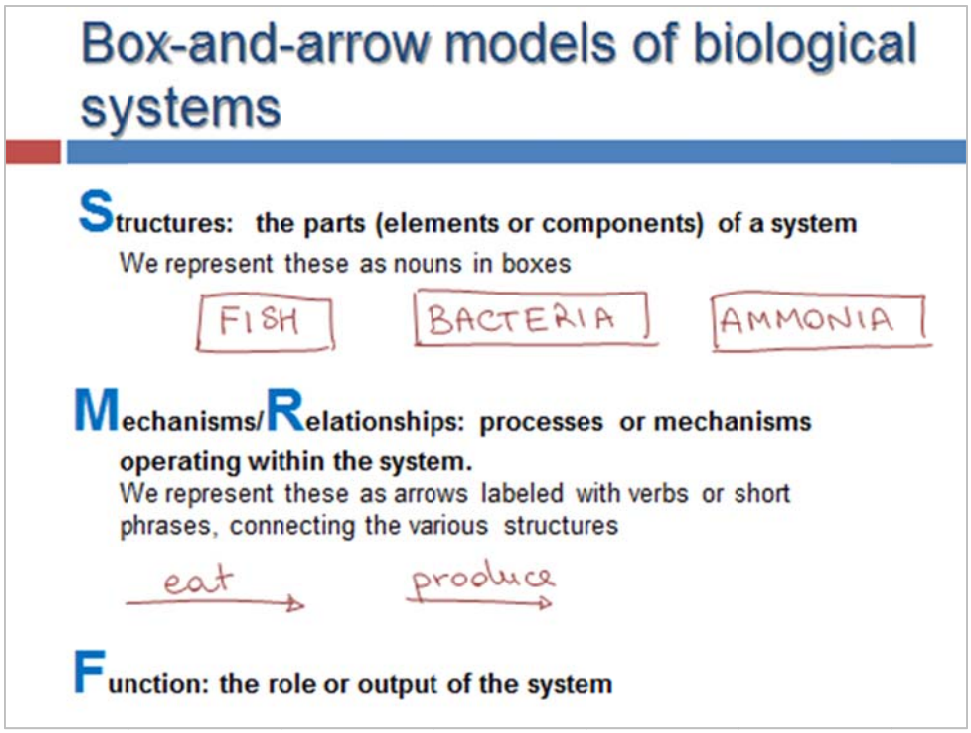
On ONE sheet of your carbonless notebook:

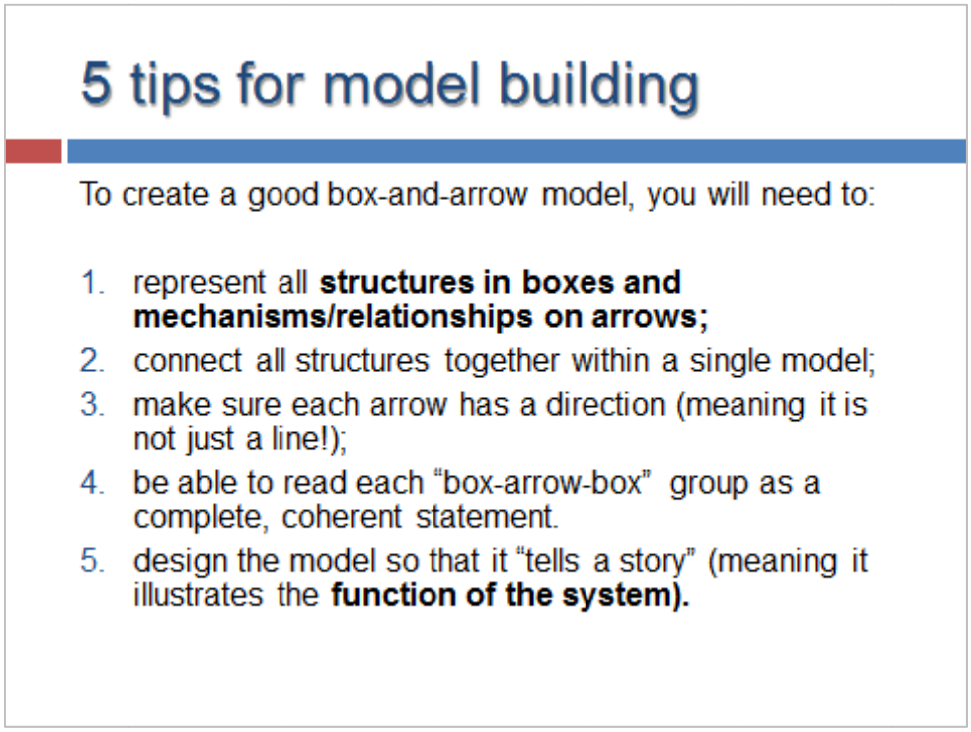
Top of the page: FIRST NAME, LAST NAME, DATE

Q1. Identify and list the biological components (STRUCTURES) of the aquarium system that are relevant to the process of nitrification (e.g.: what needs to be present for the aquarium system to accomplish the FUNCTION of nitrification?)

Q2. Construct a box-and-arrow model illustrating HOW the system becomes a mature tank (a tank where there is nitrate rather than toxic ammonia); use the structures that you identified, and connect them in a model that illustrates the system's function (nitrification).

Supplemental Materials S2. Set of practical SMRF model-building conventions presented to students by the instructor during week 2 of the course.





Supplemental Materials S3. Follow-up homework assignment, in week 4, requiring students to revise their first decontextualized DNA-to-protein models, add the new structure *gene*, and formulate a written reflection about their revisions.

Revise, rewrite and reflect.

Please, review the box-and-arrow model you discussed with your group today in class (HW 4-1; you should have your copy in the carbonless notebook).

After discussing with your group and participating in class, have you learned something new that either modifies or completes the way you would build the model? How would you incorporate the concept of gene?

Q1: On ONE sheet of carbonless paper:

Build a box-and-arrow (SMRF) model representing your current understanding of **how genetic information contained in a gene is used to make a protein**. At a minimum, use the following six structures: **gene, DNA, nucleotides, mRNA, protein, amino acids**. You can include additional structures if they help you convey the function of the model.

Q2: Type in the box below. What did you change in your model (besides, of course, adding "gene" as a structure) and why did you change it?

Supplemental Materials S4. Case study text and model prompts from exam 1 and final exam.

Excerpt from Exam 1 (Week 5**;** the entire exam was worth 56 points, students had 75 minutes**)**

***Soft shell clams** are native to the east coast of North America, but they have populated numerous regions throughout the northern hemisphere.

Soft shell clams are sensitive to a harmful neurotoxin called **saxitoxin,** produced by unicellular algae (**dinoflagellates**), particularly abundant during algal bloom events. Algal blooms (also known as red tides) occur during warm summer months when nutrient conditions and water temperature stimulate certain algae reproduction. Large populations of dinoflagellates during algal blooms lead to exposure of soft shell clams to high concentrations of saxitoxin.

The toxin affects neurons and leads to paralysis and death of sensitive clams. However, a mutation in the clam's genome results in resistance to the toxin. The mutation occurs in the gene coding for a **sodium channel** that is critical for proper function of the clam's neurons.

*Source: http://www.evo-ed.com/Pages/Clams/index.html

Model - Draw a box-and-arrow model illustrating how genotype determines phenotype in the toxin-resistant clams.

Use the following structures: **DNA, gene, allele, mRNA, protein, phenotype**. Make your language specific to the case of the clam. You may use any structure more than once, and you may include additional structures, if it helps you build a meaningful model.

Make sure you incorporate the mutation event.

Excerpt from the Final Exam (Week 16; the entire exam was worth 100 points, students had 110 minutes)

Leptin (from the Greek leptos, meaning "thin"), is a small secreted protein essential for energy balance and weight maintenance. Leptin is produced and secreted by white fat cells (adipocytes). As fat mass increases, the amount of leptin secreted increases. Leptin travels through the blood and binds to receptors in the hypothalamus. In response to leptin, the hypothalamus decreases appetite and increases the body's metabolic rate.

Genetics and Metabolism

The function of leptin was discovered by studying mutant mice that were obese due to overeating. The gene for leptin was thus named *ob*, due to the obese phenotype of the mutant animals. The *ob* mice weigh significantly more than wild-type (normal) mice. An *ob* mouse is shown below, next to a wild-type mouse.

Open-ended Question– Write on the back of the scantron

Draw a single box-and-arrow model (SMRF) model illustrating (a) **how the obese phenotype originated** in the wild-type mouse population, and (b) **how genotype determines phenotype in the *ob* (obese) mice.**

Use at a minimum the following structures: **DNA, gene, allele, mRNA, protein, phenotype**. Make your language specific to the case of the mouse.

You may use any structure more than once, and you may include additional structures, if it helps you build a meaningful model.

Supplemental Table S1. Timeline of molecular genetics SBF modeling tasks students completed throughout the course of the semester. Note: For the second half of the course (weeks 9-16), the context of SBF models was the flow of energy and matter through various systems; these models were, thus, left out of the table.

Week	***Assessment Type***	***Model Type***	***Context***
4	Homework	DNA-to-protein	Decontextualized
	Homework	Gene-to-protein	Decontextualized
5	In-class activity	Gene-to-phenotype	Mc1R protein and fur color in mice
	Exam 1	Gene-to-phenotype	Toxin resistance in clams
6	In-class activity	Gene-to-phenotype	Revision of Exam 1 VtP model
8	Exam 2	Gene-to-phenotype *	DDT resistance in mosquitoes
16	Final Exam	Gene-to-phenotype	Leptin protein and obesity in mice

* For exam 2, students had the option of building a model or answering the same question with a paragraph. About 50% chose to build a model; since we do not have a complete set of models for this exam, we did not include them in the analysis

Supplemental Table S2. Grounded, validated rubric used to code propositional accuracy of students' responses on fill-in-the-blank pairwise assessments and relationships within gene-to-phenotype models. Students' responses were scored using a 0-3 scale, 3 signifying the most accurate response.

	3 points	2 points	1 point
DNA_mRNA	separates and is copied into a strand of; serves as a template for; is transcribed into	codes for; controls the production of; helps to encode messages to the; leads to the creation of; provides coding info to; provides a basis for creating strands of; transcribes; is transcribed by; transcription; is used to produce; uses its code to create	converts into; are copied by; copies itself to make; is made by; make; is transmitted through; turns into
mRNA_Protein	codes for; translated to produce; is translated into; is translated into amino acids that make up a; is translated by combining with tRNA and rRNA to build	carries information to make; determines which; has the amino acid sequence for; helps make; sends the genetic info to ribosomes to make; sends the messages to synthesize; transports information for	creates; directs the; makes; synthesizes; is made of different; transfers; transports
Gene_Protein	carries the DNA sequences that lead to creating a; codes for	are blueprints to make; codes into; controls synthesis of specific; could affect the usefulness/activity of; determines type of; expresses a; are turned on/off by	absorbs; contains; information comes in the form of a; is made from; are made up of; need; sends info through; are sequences of
Allele_Gene	a form of a; different version of a; variation of a	are either dominant/recessive traits in the; a type of a	consist of; determines; expressed in; expresses a; expression of; are found in; is half of a; is the information in a; makes up
Gene_DNA	is a coding section of; is composed of; is made up of	contains; are found in; made by; is a part of; is a section of; is a segment of; is a sequence of; is a unit of	comes from; composes; makes up
mRNA_DNA	is transcribed from	based off the sequences of; carries info. from; is coded from; comes from/is made from; is complementary to; gets messages through; is made by another strand of; sequence matches that of; takes information from; transcribes	codes for; copies; help in the copying of; is translated from; is transported with help from; translates
DNA_Gene	has specific coding sections called	composes; contains; has; has regions called	codes for; comes from; made up of; produces
Gene_Allele	have various versions called; mutation results in different	has; have many; mutated into new; produce different	also known as an; consists of; expresses; mutation; is part of; replicates