The Biology of Food

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After many years of teaching upper-level college biology classes, I realized that, to an extent, I was "preaching to the choir." These students were already interested in the subject matter—they had, after all, chosen to major in it—and they had moderately good science backgrounds. I decided to make a bigger impact by teaching nonscience majors (many of which have not taken biology since ninth grade).

By the time nonscience majors get to my course, they usually have forgotten much of what they learned in high school, and many hold deep-seated misconceptions. These students are smart and capable; if they have failed to grasp genetics or evolution up to this point, it is not for lack of ability. Most likely, it is because they did not make connections that enabled them to put what they learned into a context that made sense.

I attempt to provide that context by organizing an entire course around food. The Biology of Food course—a large lecture course with no laboratory section—is a mixture of kitchen chemistry, post-eating food metabolism, origins of different foods (from crop breeding to evolution), and ecological and environmental impacts of farming and harvesting practices. The material is a combination of lessons I have developed specifically for the course and information adapted from Harold McGee's *On Food and Cooking* (1984). Nearly every topic begins with the introduction of one or more recipes, followed by student investigation of the related cooking methods and ingredients. This approach ties information to experiences just enough to engage students in the material. The approach is also directly transferable for use in high school biology courses. Because there is no laboratory, options are limited, but it is essential to use inquiry-based methods. Two methods used in the course are described in this article.

Familiar contexts help students grasp complex scientific issues

The bread problem

To begin the course, I arrive the first day with two loaves of bread that I made in a breadmaker (Figure 1). One loaf is light and fluffy; the other is short, dense, and very heavy. I pose the following to students: "Here we have two loaves of bread. One turned out great. The other would make a good doorstop. We need to know what happened to make these loaves turn out differently. What do we need to know to figure this out?" Students discuss the problem in groups, and together we compile a list of responses on the board. During the discussion, students focus on the following questions:

- What do we need to know?
- What do we already know?
- What do we need to find out?

Students want to immediately work on solving the problem. For example, a few who have made bread before may ask, "Did you forget the yeast?" However, not everyone has this level of background and therefore it is important not to skip ahead. Students quickly discover what information is needed—the ingredients and process used to make the bread. I list the ingredients for students: milk, flour, an egg, sugar, and yeast. I state that I used the same

set of ingredients for both loaves and that I put the ingredients into a bread machine and pressed "start." The bread machine then mixed, kneaded, waited (first rise), kneaded, waited (second rise), and cooked the bread. The machine treated both loaves the same way.

At this point, students realize that they need more information before moving forward. I divide the class in half and assign some students to research *flour*, and the others to research *yeast*. I then divide the class in half again (differently this time) and assign some students to find out what happens during *kneading* and the others to find out what happens during *rising*. They all must research what happens during *cooking*.

The next class meeting begins with student groups discussing their research. The research is then compiled. *Flour,* the ground seeds of wheat, contains starch and some protein. When flour, eggs, and milk are mixed, a thick suspension of starch granules and protein molecules is obtained. *Yeast* is a type of microorganism (see sidebar "Yeast," p. 32). When yeast is put into the bread dough, yeast cells eat some of the material in the dough and multiply.

During *kneading*, physical manipulation is used to unfold the protein molecules from the wheat seeds. The molecules and seeds adhere to one another, producing a network of tangled molecules called *gluten*. The gluten network traps air bubbles that are introduced by the kneading process.

During *rising*, yeast cells consume sugar and metabolize it to produce carbon dioxide (CO_2) and ethanol. The CO_2 diffuses into the air bubbles that are trapped during kneading, which causes these bubbles to expand. The dough rises because the gluten network traps the air bubbles and prevents them from escaping.

During *cooking*, the gas bubbles expand as the temperature increases (after all, $PV = nRT$). The loaf rises further—the classic "oven spring"—until the temperature is high enough for the starch to gelatinize and solidify the loaf and ultimately kill the yeast. (Many television advertisements for store-bought chilled or frozen breads and pastries show time-lapse movies of bread, cookies, turnovers, or biscuits expanding rapidly in the oven. This rapid rise is called *oven spring*.)

I then ask students, "What happened with the heavy loaf that I made?" I encourage students to break the heavy loaf open to see that the ingredients are well mixed, but that the loaf contains only very small air pockets. I make sure to let students know that under no circumstances can they eat the bread—no eating is allowed in the classroom. Students conclude that the air

FIGURE 1

Two loaves of bread.

One loaf that is light and fluffy and another that is short and dense are shown to the class at the beginning of the course.

pockets must not have expanded during the first and second rise. The easiest explanation is that the yeast added to the mix was dead, and the yeast packets used must have been expired. (I actually cheat to ensure that the second loaf doesn't rise by microwaving the yeast.)

Students learn several things from this exercise:

- A step-by-step method of problem solving;
- How breadmaking works;
- The composition of wheat endosperm (which can be addressed when discussing seeds);
- The nature of a particular species of fungus, yeast, and some of its metabolic properties (which can be addressed when discussing fermentation and winemaking);
- The principle of protein unfolding (which can be addressed when discussing omelet-cooking and cheese-making); and finally
- Students make the connection between biology and physics, as they think about how CO_2 makes the air bubbles expand, and how cooking makes the bubbles expand even further.

Feedback from students is usually enthusiastic. Often students claim that they have "never thought about bread that way before." Furthermore, students complete most of the work themselves, though I help them put the information together at the end.

The fish harvest scenario

I use a different "gimmick" when students start analyzing a recipe for poached salmon. I could list the fish stocks that are in decline from overfishing, describe the features of endangered populations, and encourage better stewardship of the Earth. Instead, I begin class by handing out two different printed scenarios, blue to one side of the room and orange to the other (Figures 2 and 3, p. 33). The information is nearly identical on both sheets, except for one seemingly minor piece of data. Each group plays the role of biologists for a large fishing company. In this scenario, the head of the company suggests raising the harvest from 5,000 fish per year to 7,000 fish per year. I ask students, "Based on your information sheet, what would you recommend? Is this suggestion a good or bad idea?"

By giving students numbers that make the calculations easy, they can subtract the 5,000 or 7,000 fish from the total population, consider the reproduction rates and the age-to-maturity of the species, and determine whether the new harvest rate (7,000) would result in catching more fish than are produced each year. Students with the blue sheet (Figure 2) conclude that 7,000 is fine; students with the orange sheet (Figure 3) find that 7,000 is too many, and that the fish will be depleted.

The discussion is interesting because both groups perform the same calculations, with the same population size and harvest rates, but they reach opposite conclusions. This startles students. The only difference is the *age-to-maturity* factor (in reality, orange roughy do take quite a long time to reach sexual maturity), a characteristic that students don't think to consider.

The numbers are imaginary, selected to make the two scenarios identical in all respects but one, and the mathematical algorithms are designed for ease of use to facilitate the comparison. Nonetheless, the

Yeast.

Although there are many species of yeast, in many genera, the one used in baking and brewing is *Saccharomyces cerevisiae*, "brewer's sugar fungus." The history of baking and brewing are intertwined, with old beer initially used as the starter for baking, and old bread dough sometimes added to barley malt to initiate fermentation. Now, many specific strains are used for different applications. The brewing and winemaking strains, for example, have been selected for tolerance of high alcohol concentrations.

It is interesting that although the same biochemical processes are involved in baking and brewing, different products are favored. In baking, the CO_2 is used to make bread rise and the ethanol is evaporated during cooking. In winemaking, the ethanol is saved and the CO_2 is allowed to escape. In brewing beer, both ethanol and CO_2 are saved.

Lead-in to student research.

The use of easy-to-calculate numbers has its value in streamlining the comparison to engender student interest. Once this has been done, it is possible to ask students to find out what the *real* numbers are. Their research should lead to mixed results. Age-to-maturity, lifespan, and geographic distribution can be determined accurately. However, it is hard to count all the fish in the sea, so we resort to using the annual catch as a proxy for population size. It is a poor proxy, since increases in fishing efficiency can mask declines in population size.

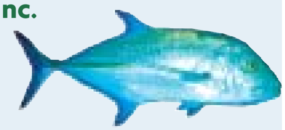
Fish and soybeans: Plant/animal coevolution.

Many land animals, including humans, have been in an arms race with plants. Herbivory by animals selects for toxin production in plants, which, in turn, selects for toxin tolerance in animals. Many legumes produce defense toxins. Humans are able to tolerate those toxins in soybeans; trout and salmon, however, are not. In the wild, trout and salmon are carnivores and did not encounter soybeans in their evolutionary history. Their sensitivity to soybean toxins has been revealed as fish farmers have turned to soybean meal as an ecologically preferable food, compared to fishmeal. As noted by Snigdha Prakash (2004), the fish consequently sulk. Research is underway to identify and eliminate the toxins.

FIGURE 2

Blue fish harvest scenario handout.

Buddy Bill's Bluefin Boats, Inc.



You are the fisheries biologist in a large fishing company. The Boss comes to you and says, "We've been catching 5,000 fish per year. But the population is 100,000 fish. Surely we can increase the harvest to 7,000 per year. We'd make more money if we could sell more fish! Before we do, though, I want you to determine what effect it will have on the population. Figure it out—use the same rules as always: We only catch adults, so the young will be able to restore the population. Get back to me this afternoon."

You'd better figure this out...

Bluefin have a 30-year lifespan. It takes them 6 years to reach maturity. Let's estimate that 6/30 are immature, and 24/30 are mature adults. Out of a population of 100,000, how many adults are there?

Before, we harvested 5,000 adults per year. After catching them, how many adults were left in the population?

In any given year, the adult fish reproduce, giving about 10 percent as many new fish as there are adults. Therefore, how many new fish do we get from this population (after harvest)?

This was more than we were harvesting. No wonder it worked so well year after year.

What if we harvest 7,000 adults per year? After catching them, how many adults will be left in the population?

With the same reproduction rate as before (new fish ≈ 10 percent of the number of adults), how many new fish will there be after catching 7,000 adults?

Is this more or less than the 7,000 the boss wants us to catch?

What should you tell the boss this afternoon?

FIGURE 3

Red fish harvest scenario handout.

Old Red's Orange Roughy Operation

You are the fisheries biologist in a large fishing company. The Boss comes to you and says, "We've been catching 5,000 fish per year. But the population is 100,000 fish. Surely we can increase the harvest to 7,000 per year. We'd make more money if we could sell more fish! Before we do, though, I want you to determine what effect it will have on the population. Figure it out—use the same rules as always: We only catch adults, so the young will be able to restore the population. Get back to me this afternoon."

You'd better figure this out...

Orange Roughie have a 30-year lifespan. It takes them 12 years to reach maturity. Let's estimate that 12/30 are immature, and 18/30 are mature adults. Out of a population of 100,000, how many adults are there?

Before, we harvested 5,000 adults per year. After catching them, how many adults were left in the population?

In any given year, the adult fish reproduce, giving about 10 percent as many new fish as there are adults. Therefore, how many new fish do we get from this population (after harvest)?

This was more than we were harvesting. No wonder it worked so well year after year.

What if we harvest 7,000 adults per year? After catching them, how many adults will be left in the population?

With the same reproduction rate as before (new fish ≈ 10 percent of the number of adults), how many new fish will there be after catching 7,000 adults?

Is this more or less than the 7,000 the boss wants us to catch?

What should you tell the boss this afternoon?

comparison of the two scenarios does its job: Students are now curious about the biology. I can now address the issue, "How can we know how many fish to catch?"

At the next class meeting, each student is assigned an "identity." Identities include politicians up for reelection, scientists, environmental activists, and CEOs of big fishing operations. This time, students are given an authentic scenario from the news (see sidebar "Lead-in to student research," p. 32). The International Commission for Exploration of the Sea (ICES) has noted that the cod fishery in the North Sea is in decline and recommend at least an 80 percent cutback of harvest rates; preferably a total ban on fishing. If enacted into law, this will eliminate 200,000 jobs (Malakoff and Stone 2002; Smith 2002; Schiermeier 2003; NOAA 2004). Then I ask students, "In your role as a _________, what would you do?“ Each group of students tries to influence their politician and come up with a response. For example, do they cut back the fish harvest by 80 percent, or do they do something else?

In general, students are on the side of the fish and accept the ICES recommendation. In reality, however, the European Union compromised on a mere 40 percent cutback.

I have found it quite helpful to use this kind of scenario in class. Students are given opportunities to discuss options among themselves and discover that they are not alone in failing to have the answer at the tips of their tongues. Students work through the scenario and discover for themselves an important scientific point related to that scenario. Their interest and understanding become apparent through in-class assessments (minute papers), overall enthusiasm, and more accurate and informed papers.

By relating the information to food, it is possible to link the science to students' daily lives. This gives them a way to relate new information to things they already know, enabling them to learn the material more easily.

Additional food connections

Other issues exist that can be introduced through foods. Muscle physiology is an obvious choice for meat eaters. Neuron function is necessary to understand hot peppers. Genetics is needed to explain crop breeding, which is essential to understand the origin of corn, or how Europeans developed bell peppers from the hot peppers Columbus brought back from the Americas. To understand spices, it is essential to know how plants protect themselves from being eaten by producing strongly flavored compounds (sometimes toxic compounds). To understand the origins of these compounds, we must delve into evolutionary principles and plant/animal coevolution (see sidebar "Fish and soybeans," p. 32). The increasing use of genetically modified foods is all over the news, which requires understanding natural selection and biodiversity. Hamburgers lead easily to the study of bacterial antibiotic resistance. Mayonnaise is a terrific introduction for water structure, H-bonding, and hydrophobic interactions, which makes the subsequent discussion of protein folding and unfolding remarkably easy for students to follow.

The focus on food and recipes offers a particularly good entry into genetics and evolution. Where do we get bread flour and cake flour? Before the advent of the current flourmills, we used soft wheat (for cake flour) and hard wheat (for bread flour)—two varieties that are genetically distinct. In another example, I provide my favorite recipe for grilled pork tenderloin, brushed with an ancho-guajillo-pasilla dry rub, and plated on a bed of roasted sweet peppers with chipotle Hollandaise. This recipe uses five different varieties of chiles: Where did these varieties come from? These questions lead directly to a discussion of genetics, mutation, and crop breeding.

Why are mole negro, vindaloo, and Thai curry so different? They are prepared the same way: grind up some plant materials to make a sauce for chicken. What about ravioli, chaio tzu, and empanadas? They, too, are prepared the same way, but are wildly different dishes. These comparisons illustrate that variations in foods from different cultures are not necessarily the result of differences in human ingenuity. They reflect differences in the plants and animals that are available locally. Where do these differences come from? The answer, of course, is natural selection, genetic drift, and plate tectonics—natural evolutionary processes.

By discussing crop breeding first, it is easy to present all of the basic evolutionary mechanisms in the guise of selection by humans. This is nonthreatening even for those whose worldview holds that Genesis, not evolution, describes the history of life on Earth. Once students understand the processes, it is relatively simple to replace "humans" with "environmental factors" as the selective agent. That this approach is effective is revealed in the comments from some of my students at the end of the semester—they understand evolution much better than they did before, and most importantly, they see that it really does *not* conflict with their religious views.

Developing an entire course around food has been an interesting and enlightening experience. It has forced me to look deeply into my own way of thinking about the foods and techniques that I encounter every day. It has been a challenge to devise methods that allow students opportunities to practice thinking this same way. It has been enlightening to discover, in some cases, how very differently this group of nonscientists views things that I take for granted. From this experience, I can offer two main conclusions. First, it is important to tie science topics into things that my students have experienced, so that the information feels relevant to them. The focus on food is one way to do this. Second, it is important to give students time to think, interact, and question. The bread baking and fish scenarios described here are examples of ways that this can be done. Not only does this approach result in increased student learning, it also makes teaching more fun. ■

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