A No-Holds-Barred
ECOLOGY CURRICULUM
for Elementary & Junior High School Students

JOSEPH FAIL, JR.

Lewis Thomas (1974) likened the world to a cell with each constituent part working together for the functional good of the whole. Oceans and atmosphere serve as a kind of cytoplasm, organisms a kind of nucleus; and as in the cell, damage to any of the vital parts of the world would be detrimental and injurious to its life function. This metaphor is useful to keep in mind when teaching ecology, and especially so when the educational targets are elementary students (Dunbar, 1999).

Very young students are capable of learning basic ecological principles and applying them to common environmental problems that affect their daily lives. This is the lesson my students and I have learned after my six years of teaching a "no-holds-barred" ecology curriculum to elementary students from the 1st to the 5th grades. It is a curriculum that includes investigative and inquiry-based laboratory problems to accompany inquiry-based teaching in the classroom. The premise of the project is that elementary and junior high school students can learn basic ecological concepts as a story which they can apply to their own world.

The year-long curriculum outlined here, taught by myself and college students working on senior research projects, includes the basic ecological concepts taught during a semester long course in college ecology. Since the college ecology course has prerequisites of general biology and chemistry, we also teach chemical and physical science, and biological concepts on a need-to-know basis. All classes are taught in a "storybook" format and students (and their teacher) are instructed to write a brief story of each weekly lesson in their notebooks.

Energy & Cells

The first class begins with an introduction to the biological basis of energy acquisition, storage, and distribution. We teach the 1st and 2nd Laws of Thermodynamics–that matter and energy are neither created nor destroyed, and that substantial energy is lost (but not destroyed) during energy transfers. We ask the students, "What happens when you eat a candy bar? Do you get all of the energy in it? Why do we become hungry so soon afterwards?" We lead the students to the conclusion that much of the energy in the food that they eat is lost [but not destroyed (1st Law)] as waste heat (2nd Law), so only a small proportion is available for thinking and playing.

We now ask, "Where does our energy to think and play come from?" We suggest that students look back to what they had for lunch - vegetables and meat – to where it comes from – plants and cows. Stressing our Laws, we determine how the plants and cows obtained their own energy, a small part of which was transferred to us. Eventually we get back to the source of Earth's energy and teach how plants trap light energy from the sun, change some of it to chemical energy, transfer some of that energy to cows, and finally transfer energy from the cows (and plants) to humans. Here we discuss the

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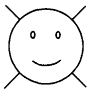
2nd Law of Thermodynamics and ask students to consider hungry children in the world and how we might feed them. Gradually we work back to the 2nd Law and, as an example of a "new idea," suggest that maybe we could eliminate animals from human diets, use plants only, and eliminate a step in the 2nd Law–demanding food chain, saving energy and perhaps lives.

Basic cell structure and function is also presented using cell models, transparencies, and living cells (*Elodea*) to observe how cells are put together. We note the structure and function of: nuclei, cytoplasm, mitochondria, chloroplasts, ribosomes, and cell walls and membranes. Microscope technique is introduced with live specimens, generating excitement for learning about biology. (Remember that the point is *not* to learn about the microscope, so spending little time on that training is useful in maximizing observation time and generating maximum excitement about the beauty of life.) In some classes, to stimulate excitement about biology, we have included microscope work in the second half hour of the very first class, looking at live *Elodea* and Wandering Jew (*Zebrina*) leaves. Students readily learn cell structures and have no problems with terminologies or definitions. They are not grilled on material and do not memorize; rather they learn structures and their functions by observing and thinking about how the cell works, and by hearing repeated pronunciations and definitions during their observations.

During these early classes we ask each student to plant a corn seed and keep track of its growth. They are asked to think of an experiment to do with their seeds, such as growing some under red, green, or blue lights, or in warm versus cool temperatures, or low versus high light levels. They are to record changes in the heights of their plants and provide guesses (hypotheses) as to the outcome of their experiments. At the end of 3-5 weeks, a class is devoted to interpretation of data and to writing. Students are taught to write up their experiments in standard scientific format, including constructing a table and a graph.

Atoms, Molecules, & Covalent Bonds

The concept of storage and release of energy leads to the introduction of the basic formula for photosynthesis and respiration:



$$\rightarrow 6CO_2 + 6H_2O \underset{R}{\overset{P}{\rightleftarrows}} C_6H_{12}O_6 + 6O_2$$

Here we introduce concepts - and terminology - associated with atoms and molecules. At this stage a molecule is the smallest particle of a "complex substance," say sugar or carbon dioxide or water, all of which we note in our shorthand formula. As we go through the formula, we repeat the words of the elements and the compounds many times.

Prior to the introduction of models representing atoms and molecules, the students have learned that light energy, during photosynthesis, breaks "bonds" (energy) that "glue" together the smallest bits of the simplest matter we can imagine – of hydrogen and oxygen atoms of water (a complex substance) in this case – so that we have even smaller bits. When the molecule becomes "unglued" (the bonds broken), then "atoms," and the energy holding them together, result. We keep stretching our imaginations. We note that, just as energy can be used to "split" molecules (such as H_2O), so can energy be used to "glue" simple molecules together to make more complex ones; such as gluing together 6 molecules of carbon dioxide with 6 molecules of water to form "sugar."

Using the blackboard, models, and the periodic table, we introduce atomic structure discussing only the elements of our formula. The students build blackboard and crayon models of atoms of hydrogen, carbon, and oxygen with help from teachers and the periodic chart. Drawing exercises are fun for elementary students and we encourage colorful atomic models. We ultimately illustrate the making of covalent bonds (trapping energy) by building a model of sugar, $C_6H_{12}O_6$ - the end result of the trapping of the sun's energy in the presence of chlorophyll - with marshmallows (C), grapes (O), and raisins (H) held together with toothpicks (covalent bonds) (Figure1).

We now illustrate the breaking of covalent bonds – the release of energy – between carbons of sugar that in turn lead to simpler molecules, carbon dioxide, and water. We emphasize that much energy had to have previously been provided in the form of light to trap little bits in the form of chemical covalent bonds. This leads to the question, "Which Law states that?"

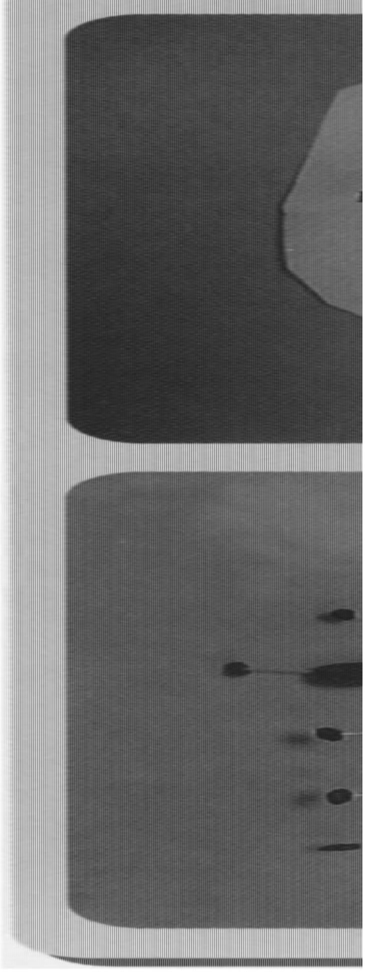
This process of making and breaking covalent bonds is the central energetic reaction that drives life. Several class periods are spent emphasizing these principles including how carbon dioxide and water are used in photosynthesis - the light and dark reactions - to make covalently bonded sugar molecules. Sugar is, in turn, broken down during the process of respiration to release energy from covalent bonds. The basic stages of these reactions can be taught simply - 3 or 4 steps - providing the essential features of how life has evolved to manage energy.

The students now begin another long-term experiment studying, through decomposition, factors that affect respiration. Decomposition is the process of respiration of the carbon compounds of dead bodies by bacteria and fungi. Fallen magnolia leaves, previously washed and dried, are used in the experiment (*M. grandiflora* provides excellent large, sturdy, and classroom-manageable leaves). Each student (or pair) chooses 3 leaves, weighs them on a 3-place electronic balance, and records the findings on paper or his/her journal kept during the course. Aluminum pie pans of potting soil are provided and students pair and set up two contrasting treatments for each set of 3 leaves. (Students have previously been given suggestions for possible experiments, such as watering one set of leaves with 10 mls of water per week versus another set with 20 mls per week. Or using two different temperature regimes, or different soil types, or any of a number of different types of treatments that will be continued for 3-4 weeks). At the end of those weeks, students wash, dry, and re-weigh their leaves and draw conclusions about support (or lack of) for their previously generated hypotheses. During the class period, students review how to write up results in standard scientific format, including preparation of a table and graph of results.

Energy, DNA, & Proteins

Now that students understand relationships between molecular structure and energy, and have basic knowledge of a cell, it is not a far leap towards understanding the biological connections between energy dynamics and its relationship to information transfer and protein synthesis. This topic is necessary for students to understand how cells manage energy, since enzymes (and so proteins) are intimately involved in all energy transfers in cells. Students must know more than just the words; they should also know that without proteins, life as we know it could not exist, and that these proteins are essential for both photosynthesis and respiration. Since students have studied an organic compound (sugar) and its covalent bond linkages, we now introduce them to other types of carbon compounds. Nucleic acids and proteins are used for this purpose because they represent covalent bond linkages and are simple (even elegant) molecules in their own right. Students now begin to investigate how information is managed in the biological world and its relevance to the management of energy.

Figure 1
Marshmall
model of a

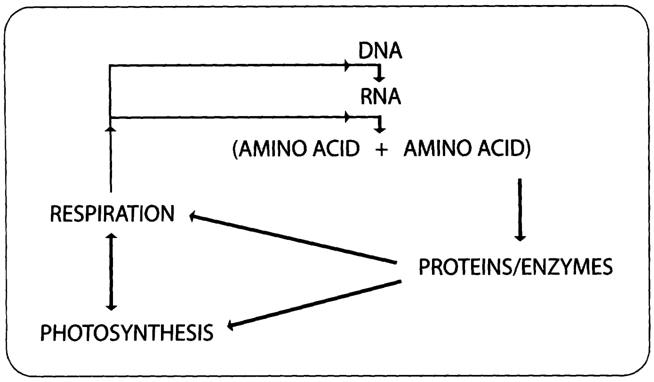


Though the molecular structure of these compounds is simple, some rigorous thinking is demanded to determine the biological connections among all of these types of molecules. Students enjoy this thinking exercise because the connections among these molecules are "discovered" by the students rather than delivered to them by the teacher, and because they are so "neat." We introduce the terms "transcription" and "translation" and define them as sequential steps in the process of making proteins. Plastic models and transparencies of the five bases that make up the molecules of DNA and RNA are used to teach the basic structure of these molecules. Covalent bonds, just as in sugar molecules, are the basic energetic glue that holds these new molecules together.

The students are now introduced to the structure of amino acids and why they are important. Their major importance, for our study, lies in the fact that they are the structural building blocks of a class of proteins called "enzymes," organic molecules that allow reactions, such as those involved in photosynthesis and respiration, to occur at lower temperatures than they otherwise would. Due to these "organic catalysts," their body temperatures are "...only 98.6° rather than 986.°" By extension, enzymes are important in the entire ecological world for their ability to allow energetically manageable reactions to occur.

Standard college textbook transparencies are used to teach the basic processes of transcription and translation. We conclude with several amino acids (our chemical alphabet) joined to each other by ever-present covalent bonds to make proteins/enzymes (our biological words). Students are asked, "How does your body know how to put amino acids (the alphabet) into the right order to make the proteins/enzymes (the words) of our body?" We don't provide answers, rather encourage and coax students to figure out that the unique DNA "code" of their bodies has been "transcribed and translated" into the protein "words" of their bodies. The depth of detail is open to the discretion of the teacher, but if there is enough class time, the complete general story of protein synthesis is understandable by elementary students.

Students are now encouraged to put together the connection between transcription and translation – that is protein synthesis – and respiration and photosynthesis. We ask them to think of a "connecting story" to come up with the following diagram:



This diagrams the relationship between protein synthesis and respiration. After studying the diagram, we ask, "Are transcription and translation necessary for respiration, and if so, why?" Students eventually reason that the answer is "yes." These two information transfer processes are necessary because enzymes are needed for each step of the process of the breakdown of the covalent bonds of sugar, and enzymes are made from covalently bonding amino acids to each other in proper (DNA coded) order during transcription and translation.

Once students understand this, we continue, "Given that transcription and translation are necessary for respiration, is the reverse true? Is respiration necessary for transcription and translation?" The answer, again, is "yes," because "dead (non-respiring) bodies don't make proteins." The conclusion is that respiration is indeed necessary as the energy supply for protein synthesis.

One final connection and question remain: "Is photosynthesis necessary for respiration, and vice-versa, is respiration necessary for photosynthesis?" We figure out that the answer is "yes"; that without photosynthesis there would be no sugar (or oxygen?) for respiration, and without respiration there would not be carbon dioxide generated to use as the building block for sugar. Students are reminded that these "energy reactions" of photosynthesis and respiration drive our biological world.

Plant Structure & Function

We turn our attention next to aspects of plant structure necessary to student understanding of the place of autotrophs – "energy trappers" and "self-feeders" within ecosystem structure and function. Plants are "collectors" of material and of energy [as contrasted to us – animals – as "dispersers" of energy (Darley, 1990)]. They are specially adapted to this function with their broad leaf surfaces, branching stems and roots providing large collecting surface areas, and with their internal structure. Students use microscopes to observe slides of leaf cross-sections and stem sections, and live leaves. Students learn, by observation, that structure is related to function. Leaves must perform two major tasks if plants are to do their work of life. One is making food in an area of the leaf constructed to concentrate chlorophyll so as to most efficiently trap light and convert it to chemical energy (covalent bonds). The other, in another area of the leaf with lots of space, is to bring in gases (CO_2) and liquids (H_2O), and release "waste" gases (O_2).

We observe prepared slides of *Ligustrum* leaf cross-sections and live Wandering Jew (*Zebrina*) leaves, explaining that gases are brought in and out through leaf "holes" or **stomates** that they see in their student-prepared live leaf sections. "Pipes" – like the students' arteries and veins, but in plants, "xylem" and "phloem" – carry water and molecules within soil solutions up the plant to leaves and stems and also transport newly made sugars throughout the plant. Students observe the pipes clearly in their cross sections of stems of sunflower (*Helianthus*).

Decomposition & Nutrient Cycles

Next we illustrate another connection between respiration and photosynthesis by the introduction of nutrient cycles. "Decomposition" is part of our energetics' general theme, as the acquisition, by bacteria and fungi, of energy trapped in covalent bonds of dead bodies. The bacteria and fungi are "heterotrophs" or other-feeders, as opposed to "autotrophs," plants for example, that make their own food. As bacteria and fungi "munch on" dead bodies, they take in some of the nutrients of the dead bodies – N, P, K, Ca, Mg (all noted in the periodic table) – to use for building their own bodies. We note some of the functional purposes that these nutrients serve; for example, nitrogen in the making of proteins, and the use of magnesium as the central atom in the chlorophyll molecule.

Nutrients not taken up by the decomposers move into soil solutions, some of which is "sucked" by plants into their bodies to perform the life functions of respiration and photosynthesis and to build new body parts – to grow. It is noted that plants are a good way for nature to store nutrients rather than have nutrients moving, say, into water bodies, that through fertilization effects, could lead to excessive growths of algae. When plants, and students and teachers themselves, die; they, too, will be decomposed – respired – and their parts recycled into new life. It is during this time that students conclude their decomposition experiments and draw conclusions about results of their various treatments.

Plants' Responses to Light & Temperature

The discussion of photosynthesis in an environmental context leads to consideration of how the process responds to temperature and light. Students learn that the process consists of two parts - a light reaction responsive to light intensity and a dark reaction responsive to temperature. Students reason what the photosynthetic rate would be "today" based on the light and temperature conditions of the particular day. They are asked what they would measure to check the rate of photosynthesis. We prod them to pay attention to the formula and figure out which compounds plants are using –carbon dioxide and water – and which compounds they are producing –sugar and oxygen – and that the rate of production of these compounds can be measured.

Freshly cut *Elodea* stems enclosed in small test tubes of water are used to test (by measurement of the rate of bubble evolution) the hypothesis that photosynthetic rates vary as light intensity and temperature vary. Quality of light is discussed as equally important as the other environmental factors (temperature and light intensity) affecting photosynthesis. Exploring the answer to the question, "Why are plants green?" returns us to our central theme, energy.

Transparencies illustrate Engelmann's 1882 experiment in which a strand of *Spirogyra* - an autotroph or "self-feeder" - was exposed to the light spectrum (ROY G BIV) of colors that can be seen by passing sunlight through a prism. Engelmann surrounded his algal strand with a shallow pool of water into which he introduced bacteria - heterotrophs or "other feeders." In time, Engelmann observed that the bacteria migrated to the red and blue ends of the spectrum.

Students are asked for their conclusions and interpretations of the results of Engelmann's experiments in light of their previous knowledge of the formula for photosynthesis and respiration. With questioning and hints, we arrive at the discovery made by Engelmann, the relationship between light quality (wave length/color) and photosynthesis, and the relationship of photosynthesis to respiration. Plants absorb the red and blue wave lengths of light and reflect green, answering the question, "Why are plants green?" Using the trapped light energy, they change a small portion of it (the 2nd Law of Thermodynamics) to chemical energy (the covalent bonds of sugar) with simultaneous loss of untrapped (but not destroyed) energy as heat and green light. We speculate on why plants have evolved to reject some of the light striking their leaves and conclude that if they absorbed it all, they would be black and too "energetic," that is, too hot. We also note that the reverse situation, being white, would also be a problem in that not enough energy would be absorbed to make the covalent bonds of sugar. Engelmann's experiment is an excellent model of how the planet works as an ecosystem.

As an "art experiment," students "design a planet and a plant that would grow on it." We suggest that the sun may be a different color than ours (or even emit radio waves or other electromagnetic radiations instead of light) and that the plant may be a color other than green. As an example, I ask them to pretend that they have a green sun in their solar system, and in that case, what color would their plants be?

The Seasonal Snake

Our ultimate goal is to teach students an unforgettable story of the interconnection of biological energy dynamics and nutrient cycles. With student help, we create a flow chart (snake) of annual seasonal changes of photosynthesis, decomposition, and nutrient uptake rates that occur in a temperate deciduous forest.

The story begins in the summer with plants "sucking" or "taking up" soil water with its load of dissolved nutrients (N, P, K, Ca, Mg), through their roots, up their "pipes" (xylem) to their leaves, and out as vapor (minus the nutrients kept by the plant), through the holes (stomates) in the bottoms of their leaves. In the fall, leaves drop, and so too, their stomates, which then leads to the cessation of nutrient uptake. Leaves on the ground, loaded with their summer-made photosynthetic sugars, are "attacked" by bacteria that "respire" these sugars and release unused nutrients into soils.

This process, decomposition (respiration), slows as winter comes, with low temperatures which stop further release of nutrients from the dead leaves. Then spring arrives, and with higher temperatures, decomposition and nutrient release rates increase at the same time that new leaves begin to appear with their stomates. This restarts transpiration ("plants suck") and renews nutrient uptake.

The process is summarized as the "Seasonal Snake" (named for its depiction as a snake-like flow chart). For elementary students, I use the name of the princess on the old Howdy Doody show - "Princess Summer-Fall-Winter-Spring's" Story of the Seasons.

Summer

Leaves with stomates present on trees. → Plants "suck" (take in water and nutrients through roots). → Soil water nutrients low.

↓

Fall

Leaves (and stomates) drop. → Nutrient uptake stops and leaves decompose (bacterial respiration). → Soil water nutrients high.

↓

Winter

Temperatures low. → Decomposition rates drop.
→ Nutrient release from litter slows. Soil water nutrients low.

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Spring

Temperatures rise. → Decomposition rates increase.
→ Nutrient release from litter increases. → Soil water nutrients high. → Leaves (and stomates) reappear.
→ Nutrient uptake by plants increases. → Soil water nutrients decrease.

The Field Trip

An ideal way to tie together these concepts is to take a fall or spring field trip to a working farm, forest, park, or other natural ecosystem or, preferably, several. At these sites the class can take trail hikes during which the teacher points out (or asks students to) real world examples illustrating the stories they have learned, including photosynthesis and respiration, decomposition, nutrient cycling, plant and animal diversity, and others, including student "new ideas." The story of the trip can be the final student write-up - the final exam - of the lessons he/she has learned during the course of the curriculum (White, 1996).

Summary

While our targets were elementary students, this curriculum is also adaptable to junior and even senior high school classes, with teachers going into as much detail as is appropriate. The point is to teach environmental stories at early ages and continue for 12 years. This curriculum can be viewed as a part of K-12 science education reform (Moreno, 1999) in which "depth is emphasized rather than breadth," and attempts are made "to connect the science learning that happens in school to (students') own experiences." As Moreno and others (Moore, 1997) have noted, science education reform must begin at the elementary level to be effective. So must environmental education. This preparation to relate students to their natural world should not be "information in, information out," nor should it be tied just to science classes, nor to a single year. Environmental study should be cross-curricular (Riley, 2000), inquiry based (Darley, 1990; Uno 1990; Hackett, 1998), experimentally verified (Fail, 1995), multi-year in depth, and taught as a story rather than as a collection of facts. Teachers need to learn in this fashion so they pass both the method and the content on to their students. The approach should also incorporate all levels of education in the teaching of the various topics (Clark, 1996). Thus college teachers and students would be able to assist elementary teachers in the presentation of environmental stories and in experimental design and execution.

These lessons, then, attempt to tie together the organic and inorganic "structure" and the energetic "function" of the biological world into a unified story. When reinforced with experimental and observational laboratories, and field trips to natural areas, they create a story that is hard to forget in the students' minds. "Hard-to-forget" environmental stories will help create a public more attuned to its natural environment and more likely to keep it that way.

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