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# "How Much Is Too Much"? Teaching Measurement and Solution Concentration through Bioaccumulation and Levels of Toxicity

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by Myrna M. Alvarez

## Overview

In 1962, Rachel Carson made a very strong statement in her book, "Silent Spring," which says, "Along with the possibility of the extinction of mankind by nuclear war, the central problem of our age has therefore become the contamination of man's total environment with such substances of incredible potential for harm, substances that accumulate in tissues of plants and animals, and even penetrate the germ cells, to shatter or alter the very material of heredity upon which the shape of the future depends." [1]

This is what we are witnessing today. We have seen an alarming increase of incidents that have irrevocably affected man's total environment. From the 1940's to the present, we have observed how chemical agents have resulted in death and serious consequences. We have heard about how the Chernobyl Nuclear Accident in 1986 resulted in approximately 93,000 deaths and predictions were that about 270,000 people would most likely develop cancer. [2] In India, we have heard of news reports about the Bhopal Gas Tragedy in 1984 where a leak in a pesticide plant caused thousands of deaths and exposed hundreds of thousands of people to toxic gases. [3] We have read volumes of articles that discussed the usefulness of DDT, (dichloro-diphenyl-trichloro-ethane) as a pesticide, especially during World War II, when there was a great need to protect troops from insect borne-diseases. [4] But, using DDT resulted in some serious surprises. The first serious surprise of DDT use, was the rapid evolution of insects' resistance to pesticides that created a continuous demand for new products. Second, scientists discovered that residues often persisted longer and traveled farther in the environment. Third, residues were found accumulating in plant, animal, and human tissues. And fourth, diverse ways that living organisms accumulate, and get adversely affected by pesticide residues from exposures to contaminated food, water, soil, and air, completed the view that pesticides threatened human health, biological diversity, and basic ecological processes.

In food chains, it is the producers, the plants, some forms of algae and bacteria that provide other organisms the food and energy they need to survive. These producers can put together inorganic substances, like water and carbon dioxide from their environments, and form starch and oxygen gas. This is the process of photosynthesis. But while photosynthesis is taking place, chemicals are accumulating in tissues of various living organisms, like the phytoplankton in marine ecosystems. Other marine life forms feed on the phytoplankton. These other life forms are the consumers. These consumers do not have the ability to trap the energy from the sun; therefore, they also cannot perform photosynthesis. They depend on photosynthetic organisms for survival. Those bigger and stronger consumers will feed on smaller organisms, creating a chain. And, as the chain continues, chemicals are also moving and building up among organisms.

Photosynthesis is a complex process, so, I will start with an activity on "Starch Pictures." [5] As students develop the "starch pictures," they will acquire a concrete visualization that starch is produced in photosynthesis. I will then show videos and animations that will demonstrate that, as photosynthetic plants manufacture starch, toxins are also absorbed from their environments. I know videos and animations are not sufficient for my students to really "experience" the process of bioaccumulation, so, I created the "Bioaccumulation Game." Using this game as a teaching tool for bioaccumulation, I will show, using colored candies, how a particular toxin-containing candy accumulates at the last person representing the organism in the highest level of the food chain. Learning will be more fun, and the complex concept of bioaccumulation, will be easily understood. After the "visualizing, concretizing, and experiencing" strategies, I will use case-based teaching. I will take advantage of this teachable moment to integrate measurement and solution concentration. As students enter data gathered from their case studies, I will use this engaging activity to introduce units and unit conversion. As they analyze the bioaccumulation cases and establish the toxicity level of chemicals, I will introduce various ways in which solution concentration can be expressed.

As I teach the unit, I intend to cover/review biology content areas like forms and kinds of energy, parts of the cell, populations, and ecosystems. Chemistry content includes states of matter, elements and compounds, symbols and formulas, chemical reactions and equations, and stoichiometry. This unit is limited only to the study of accumulation of heavy metals present in pesticides. Hydrocarbons, plastics, and chlorofluorocarbons are discussed only as they relate to environmental contamination. Their properties and toxicity levels will not be utilized in the teaching of measurement and solution concentration.

My four-week curriculum unit is designed for ninth grade honors biology and tenth grade honors chemistry at Dunbar Vocational Career Academy. All classes, including science courses with laboratory components are taught daily, in 45-minute periods. In biology, I will teach this unit the whole month of October. In chemistry, I plan to use this unit as the culminating activity in the last four weeks of the first semester. This unit is aligned to Goals 11, (Principles and Processes of Scientific Inquiry), 12, (Fundamental Concepts and Principles of the Life, Physical, and Earth/Space Sciences), and 13, (Relationships Among Science, Technology, and Society), of the Illinois State Standards in the teaching of science.

## Objectives

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My curriculum unit is directed towards accomplishing four important goals. First and second, using concepts on bioaccumulation, persistence and toxicity levels of chemicals in pesticides, I want my students to develop measurement skills and learn how to express solution concentrations qualitatively and quantitatively. Third, they will apply these science skills in understanding the basic principles of green chemistry and fourth, I will create awareness on the overall implications of what chemistry creates, uses, and destroys, that can be translated into making wise decisions in whatever they do everyday.

We often say that values are caught not taught. I believe, for values to be deeply rooted and manifested, they must be both caught and taught. The 12 Principles of Green Chemistry are, in my opinion, very effective tools that can guide them to be concerned and effective citizens. As high school students, they should be conscious and mindful of their responsibilities in maintaining a healthy and safe environment. They can contribute significantly as they segregate wastes at home and in school, when they conserve water as they shower and brush their teeth, when helping clean the house and the classrooms, when they use less and less plastics and its products, when they walk rather than drive short distances, and when they turn off unnecessary lights and appliances.

**The 12 Principles of Green Chemistry** [6]

1. Prevention

   It is better to prevent waste than to treat or clean up waste after it has been created.

2. Atom Economy

   Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. Less Hazardous Chemical Syntheses

   wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. Designing Safer Chemicals

   Chemical products should be designed to effect their desired function while minimizing their toxicity.

5. Safer Solvents and Auxiliaries

   The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

6. Design for Energy Efficiency

   Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

7. Use of Renewable Feedstocks

   A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. Reduce Derivatives

   Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized and can generate waste.

9. Catalysis

Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. Designs for Degradation

    Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

11. Real-time analysis for Pollution Prevention

    Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. Inherently Safer Chemistry for Accident Prevention

    Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

## Rationale

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Measurement is one basic skill necessary for life. Whatever we choose to become in life, a doctor, a pharmacist, a plumber, an auto mechanic, a teacher, or a scientist, we need measurement skills. When a baby is born, weight and length are recorded; when we buy gas, gasoline pumps give volume measurements. When we go to supermarkets to buy groceries, meat, poultry products, and produce, we see these things packed and labeled with appropriate mass or volume amounts. When driving, we are guided with road signs showing distances between two destinations. When traveling across states, we consider temperature and weather forecasts. In gyms and workout areas, treadmills and other machines show calories lost, distance traveled, and even pulse and heart rates. At home as mothers, we exercise caution in measuring milk formula. In whatever we do, there is always something that needs to be measured.

Every year, it always bothers me to see students who cannot even identify units of length in a meter stick. In ninth grade, they come to my biology class not equipped with simple measurement skills like getting the volume or finding the mass. Most often, they cannot give accurate mass or volume measurements using ordinary weighing scales or simple beakers. One time, when I was discussing how each laboratory apparatus is used, I asked one student to prepare fifty milliliters of water. With confused eyes, she grabbed the graduated cylinder and filled it up to the brim. In the mole lab activity for chemistry last school year, I asked students to measure the masses of different substances. When I checked their recorded data, I saw masses in kilograms and I found it absurd because the largest mass I prepared was 64 grams of copper. Units of measure baffle them. I realized then, that measurement, for them, is one very challenging activity. Thus, when faced with simple tests having problems on dimensional analysis, they get scared or frustrated. I get the same response teaching solution concentration and mole problems. Most of my students simply turn their backs and decide not to do any thing at all. This worries me more. And, I, as a teacher believe, it is my responsibility to think of more effective strategies and relevant lessons that will make them more motivated and engaged in learning. And, I also believe, using issues with personal and social significance like bioaccumulation of toxic chemicals, I can realize my goals and develop in my students the necessary skills needed in future studies and in the world of work.

## Background

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**Photosynthesis**

Humans and all living things depend on photosynthesis for nourishment. Photosynthesis completes many of our needs. It provides fiber and building materials. It fills the need for energy by storing it in petroleum, natural gas, coal, and even firewood. This is also the process that produces the oxygen that makes up a portion of the earth's atmosphere. Plants, some forms of bacteria and algae produce food by this process. These autotrophs are capable of synthesizing food directly from inorganic compounds, like carbon dioxide and water to produce sugar and oxygen gas. Later, when plants need food, they draw upon the energy stored in these sugars.

In photosynthesis, light energy from the sun is captured using the pigment chlorophyll. These pigments are contained in organelles called chloroplasts. Although all green parts of plants have chloroplasts, most of the energy is produced in the leaves. The cells in the interior part of a leaf, called the mesophyll, contain about half a million chloroplasts for every square millimeter of leaf. [7]

Photosynthesis, as shown in Figure 1, occurs in two phases, the light dependent and the light-independent reactions. Light dependent reactions convert light energy to chemical energy in ATP (adenosine triphosphate). The energy in ATP is used to produce simple sugars in light-independent reactions. The general equation for photosynthesis is:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

The first phase of photosynthesis needs sunlight. When sunlight strikes the chlorophyll in the leaves, energy from light is transferred to the electrons in the chlorophyll molecule. The energized electrons are passed from chlorophyll to a series of electron acceptors in the thylakoid membrane, which is called the electron transport chain. Each electron acceptor in the chain passes energized electrons to the next one. At each step, the electrons lose energy. Some of the energy is then used to pump hydrogen ions into the center of the thylakoid disc. After traveling along the electron transport chain from photosystem II to photosystem I, the electrons get re-energized and are transferred along a second electron transport chain. At the end of the second chain, the electrons are still energized. Finally, the electrons are transferred to the stroma of the chloroplasts, where an electron carrier, $NADP^+$ (nicotinamide adenine dinucleotide phosphate) is used. $NADP^+$ combines with two energized electrons and a hydrogen ion ($H^+$) to form NADPH. NADPH stores the chemical energy that will then be used in the light-independent reactions.

Used electrons in the chlorophyll molecule are replaced by breaking the water molecule. For every water molecule that is broken, one half molecule of oxygen, two electrons, and two hydrogen ions are formed. The oxygen is released in the atmosphere. The electrons are returned to the chlorophyll while the hydrogen ions are pumped into the thylakoid where they build up in high concentration. With the concentration difference across the thylakoid membrane, hydrogen ions can be transferred across the thylakoid membrane and provide energy for the production of ATP.

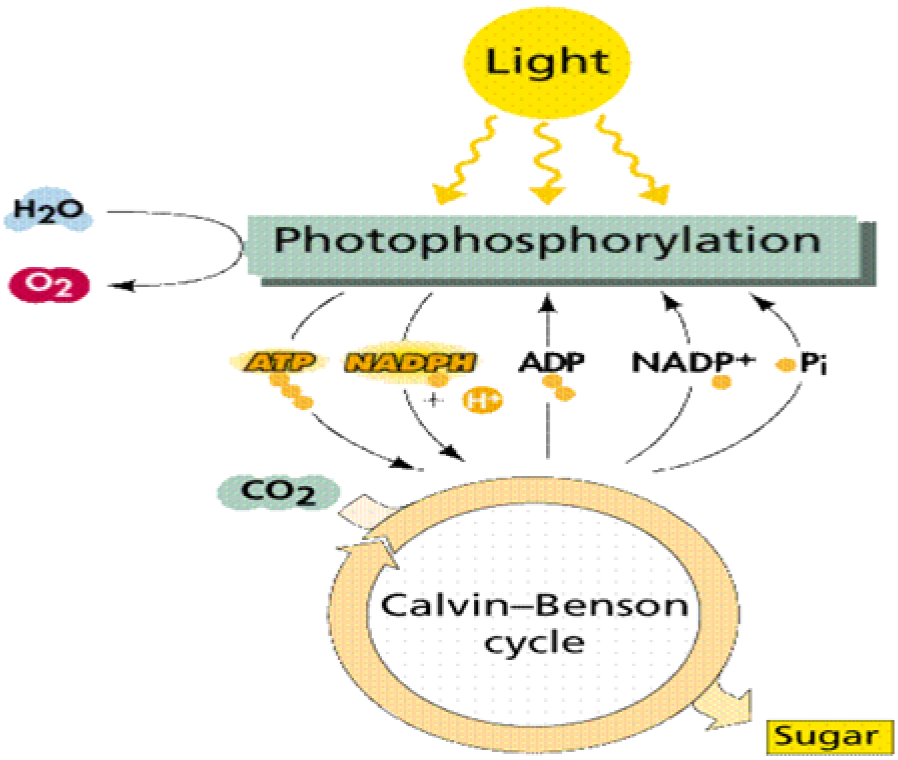


Figure 1: The Process of Photosynthesis. [8]

The second phase of photosynthesis does not require light. It takes place in the stroma of the chloroplast. The carbon in $CO_2$ is added to one molecule of RuBP (Ribulose biphosphate) via the carboxylase enzyme, a very abundant protein in the chloroplast, and form sugar through a series of reactions in the stroma. The NADPH and ATP produced during the light reaction are used in the cycle.

The process of photosynthesis is a perfect example of atom economy where both reactants, (water and carbon dioxide) are all turned into products (sugar and oxygen gas). This process also gives scientists the needed background to look for more sustainable ways that energy could be generated, so that society would have alternative sources of power for man's various needs.

**Photosynthesis and Bioaccumulation in Food Chain and Food Webs**

Energy moves from plants and some forms of algae and bacteria to animals. This energy moving up the food chain comes from the sun. Animals cannot get energy directly from the sun so they need help from smaller living things that can make their own food. In the Arctic Ocean, for example, little greenish organisms called phytoplankton are the energy sources. They can, like ordinary plants, synthesize food from water and carbon dioxide. From these phytoplankton, the sun's energy moves up the chain. Phytoplankton are usually eaten by zooplankton, the zooplankton are eaten by arctic cod, and the arctic cod are eaten by seals, whales, or sea birds. Then, bigger animals like the polar bears will feed on some of them, like the seals. In the arctic region, the northern people eat wildlife, so humans also occupy the top of the chain. As energy moves up the food chain, there is less and less energy available for use.

An opposite scenario can be observed as hazardous chemicals move up the food chain. When a toxin is picked up by smaller organisms and passed it on to bigger predators, bioaccumulation causes an increasing concentration. Because many toxins are hydrophobic, they do not mix or dissolve in water. They cannot be excreted or flushed out. So, these substances build up in fatty tissues and magnify. An example of this phenomenon is found among the plankton that absorbed about 5 parts per million of the insecticide DDD in Clear Lake, California. Plant-eating fishes had built up accumulations ranging from 40 to 300 parts per million; carnivorous species like the brown bullhead had an astounding concentration of 2,500 parts per million. [9] Bioaccumulation is seen greater among the predators at the top of the food chain.

**Bioaccumulation of Toxic Substances**

Life begins with photosynthesis. Nutrition and energy flow begin in this process. This allows plants and other photosynthetic organisms to get nutrients necessary for survival. Humans rely mostly on plants to have a constant supply of natural vitamins and minerals. But eating greens does not always mean eating healthy. Having fruits and vitamins in our diet does not always mean freedom from toxic chemicals. Trees, foliage, and plants flourish because farmers often use substances like pesticides. And these chemicals persist and concentrate in living cells. This is bioaccumulation. This is how toxins enter the food chain. Pesticides are especially interesting chemicals because, first, they include a very diverse set of synthetic and natural toxins that include insecticides, fungicides, rodenticides, herbicides, and algaecides; second, because they must be normally be released into the environments to be effective, which makes contamination of water, air, soil, and wildlife difficult to control. [10]

In 1798, Thomas Robert Malthus, an English clergyman and economist, published an essay about populations inevitably tending to grow faster than their food supply. This indeed happened. Since Malthus' time, the world population has increased from less than 1 billion to over 6 billion. [11] The need for food escalated, and agricultural scientists looked for ways to increase food production. A German chemist, Justus Von Liebig, (1803-1873), pioneered in identifying chemical substances that plants require for healthy growth. [12] As a result of his work, farmers began increased amounts of natural fertilizers to supply plants with the needed nutrients. The need for increasing amount of fertilizer led directly to the introduction of synthetic inorganic fertilizers.

Chemical use in farming grew across the continents. In the Philippines, the increased production of rice that made the country one of the major exporters of rice in Asia was due to the use of chemical farming, an initiative started by the International Rice Research Institute in the 1960's. [13] The Institute was home to the Green Revolution that led the region to rapidly increase rice yields and overall production.

Agriculture business grew, and the law of supply and demand resulted in the transportation of plants and produce brought from one place to another. The importation and exportation of plants and plant products caused the spread of pests. One example was the Colorado potato beetle that was brought by wagons to Illinois in the 1860's. [14] The spread of pests affected not only the local breed of crops in an area but those that were imported as well. There was a disruption of ecosystems. As a result, crop prices fell, the economy was hit, and the world faced massive health-related problems. This phenomenon paved the way for chemical use to kill pests and insects. It started in the 1870's when Paris Green was put to tests against the potato beetle. [15] Then, other substances were introduced like the mixtures of sulfur and lime sprayed in orchards. The failure of other methods to meet public demands for ways to stops insects without long, expensive research, changing farming practices, or long-term planning paved the way for the triumph of chemicals. In less than two decades of their use, the synthetic pesticides have been so thoroughly distributed throughout the animate and inanimate world that they occur virtually everywhere. [16] And now, it can be noted that there has been a tremendous increase in the production of synthetic pesticides from the time they were introduced in the market until today.

*Pesticides*

A pesticide is any substance or mixture intended to preventing, destroying, and mitigating pests. A pesticide can be natural or synthetic. An example of a natural pesticide is a pheromone, while DDT is the most well known synthetic pesticide. Pesticides do not only include insecticides. There are other kinds serving the same purpose but targeting different kinds of living organisms. In the United States, the Environmental Protection Agency (EPA) is responsible for regulating the production and use of pesticides. The introduction of synthetic pesticides has helped made U.S. agriculture a profitable enterprise. But often, certain species developed resistance to the chemical. The total use of pesticides in 1997 was approximately 4.6 billion pounds of active ingredients, and in the same year, more than 500 species of insects and more than 150 types of fungi were found resistant to some pesticides. [17] As a result, pesticides were combined, applications were increased, and more toxic and ecologically hazardous pesticides were used. Nearly 325 active ingredients of pesticides are permitted for use in 675 different forms of food, and residues of these compounds are allowed by law to persist at the dinner table. [18]

Both pesticides and insecticides were seen effective in increasing yield and making produce fresh looking and enticing in grocery stalls and markets. One very well known insecticide is DDT. In 1945, it was first utilized against potato beetles and cloth's moths and later became synonymous to insect control. [19] But, studies conducted after that indicated that the chemical could accumulate in living tissues because it was fat-soluble. It was also observed to be very persistent and mobile because residues were found in cow's milk even if the substance was sprayed in empty barns. Residues also linger, lodge, and magnify in the bodies of organisms that are higher in the food chain. Consider looking at the building up of these poisons. They pollute the air, the lands, and the waters. Their residues linger and become more potent and powerful as they magnify and extend beyond limits of contamination. Think about the risks we take as these substances accumulate in different plant parts and move through various trophic levels. In humans, they are not only poisons; they destroy enzymes and prevent normal functioning of body systems. According to various studies, individuals with no known exposure store an average of 5.3 parts per million to 7.4 parts per million. Agricultural workers had an average of 17.1 parts per million and workers in insecticide factories had a very high 648 parts per million. [20]

*Heavy Metals*

Another reason why insecticides and pesticides were considered threats to humans and to the environment is they often contain heavy metals like mercury, copper, nickel, lead, chromium, and cadmium. [21] These heavy metals have atomic masses greater than the masses of those of the useful metals like potassium, calcium, and magnesium. Their ions are also noted for toxicities. They are the chemical elements with a specific gravity that is at least 5x the specific gravity of water. Other scientists defined these as those with elemental densities above 7 g/cm$^3$. [22] They are found naturally in the earth's crust and can enter the human body in very small amounts through the food, water and air. They are important as trace minerals but, at greater amounts, they can lead to poisoning. There are also some nonmetals like arsenic and selenium that have the ability to magnify in living systems. In West Bengal, India, where 800,000 people drank well water containing over 50 mg/L arsenic, 200,000 people developed skin lesions from drinking the water. In Bangladesh, 70 million people drink well water containing arsenic and they exhibited similar symptoms. [23]

The periodic table in Figure 2 below, shows metals classified as: Class a: hard metals; Class b: soft metals; and

Borderline: intermediate metals. The terms "hard" and "soft" were used to denote the kinds of acids the metals formed. Hard metals form hard acids. Hard acids are compounds characterized by ionic bonds. These compounds are found mobile in living systems, and can be easily displaced or flushed out. Soft metals, on the other hand, form soft acids that have covalent bonds. Soft acids are compounds that are observed immobile and accumulate in living systems with resultant toxicity. The metals included in the Borderline category exhibit Class a and Class b properties. The heavy metals discussed in my unit are mostly found under Class B and Borderline. Some fall under both categories; like, copper may be either Class b or Borderline depending upon whether it is Cu(I) or Cu(II), respectively; lead may be either Class b or Borderline depending upon whether it is Pb(II) or Pb(IV), respectively; and iron may be either Class a or Borderline depending upon it is Fe(III) or Fe(II), respectively.

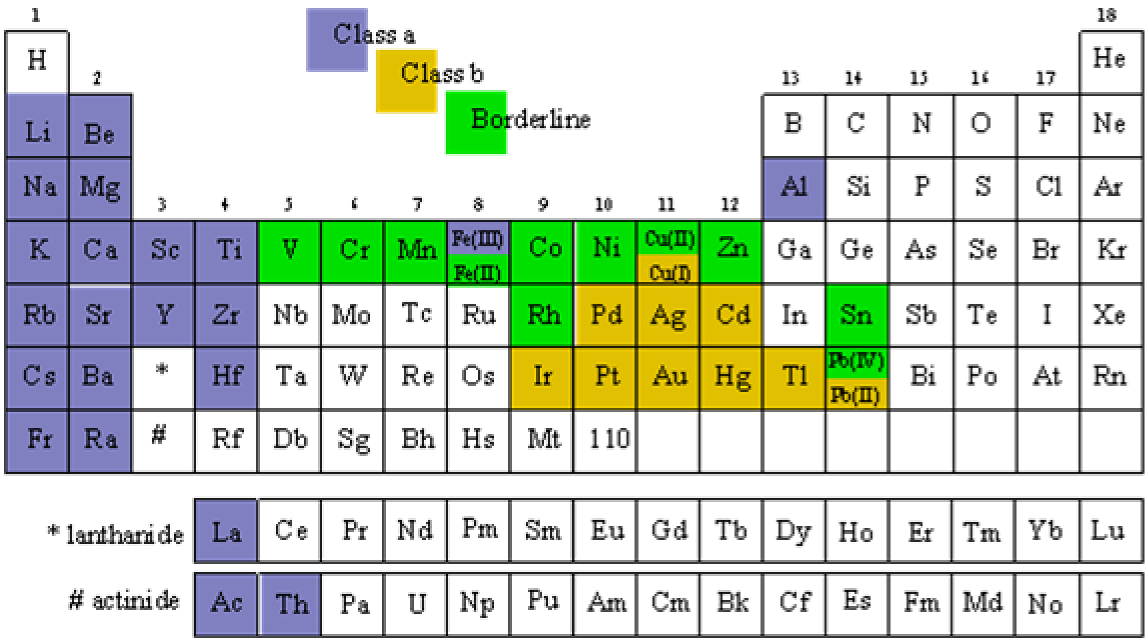


Figure 2: Periodic Table Classified as to Classes (Heavy Metals in Class b, and Borderline). [24]

Chromium: In one of my discussions with a friend, we agreed that the moment we are born, we are already contaminated with many substances. We live in contaminated environments, using contaminated products. Heavy metal contamination is observed all throughout the globe. Look at the Superfund Sites in Alameda California. Alameda Naval Station is a facility built to provide materials support to the navy. Wastes discharged from the manufacturing facilities are discharged to Seaplane Lagoon and to two on-base landfills. These wastes included industrial solvents, pesticides, cyanides, and the metal chromium. [25]

Chromium (Cr) has atomic mass of 51.996 amu. It can be hexavalent, a form that is toxic, mutagenic, and carcinogenic. Saying so, wide spread of chromium in the environment poses a serious threat to humans and animals. Its chromate ion ($CrO_4^{-2}$) has high solubility in soil and ground water and tends to be mobile. It is actively transported in cells where it was found to be capable of causing lesions in DNA. [26] Hexavalent chromium ($Cr^{+6}$) is also found to cause irritation to the lining of the nose, nose ulcers, and breathing problems. Animals exposed to the ion showed sperm damage. [27]

Lead: Lead has the symbol Pb coming from the Latin name Plumbum. Its atomic mass is 207.2 amu. It is the most recycled metal and it is used in the manufacture of many things like alloys, pigments, and ammunition.

Lead is also important in making pottery, automobile electrical storage batteries, solder, cooking vessels, pesticides and paints. Lead exposure and contamination can come from food and water. Lead water pipes are still in existence in some countries even if they can cause lead poisoning. Lead can also come from the air when it is added to gasoline to produce better burning automobile fuel. The lead enters the atmosphere through automobile exhaust as lead oxide. Lead can adversely affect children and women of childbearing age. In the past, its durability made it an excellent paint additive; thus, at one time, baby cribs were painted with lead-based paints. The sweetness was a temptation for young children and this resulted in infant deaths and other illnesses. Children are more susceptible to lead because they are much smaller and will receive a much higher dose given the same exposure. The Center for Disease and Control assigned the unit mg/ dL to be the common biomarker of lead exposure in the blood lead level. For adult male workers, the level of concern is at 40 mg/ dL. For children, it is noted to be 10 mg/ dL. [28] Toxicity symptoms include lowered IQ, memory, and learning difficulties, behavioral problems and developmental and nervous system disorders. [29]

Mercury: Mercury is the only metallic liquid element and has an atomic mass of 200.59 amu. Its symbol is Hg from hydrargyrum, meaning quick silver. The major source of mercury is the earth's crust, during volcanic emissions. It is an ingredient for many consumer products, an excellent electrical conductor, is found in medical and weather thermometers, thermostats, mercury-vapor street lamps, fluorescent bulbs, and paints. It is also famous for dental amalgams. There are two forms of mercury, the inorganic and the organic (methyl) mercury. Mercury compounds are toxic, but they are useful in eliminating bacteria, fungi, and agricultural pests when used in antiseptics, fungicides, and pesticides. Inorganic mercury can be absorbed as liquid and its vapor is hazardous because it gets converted to methyl mercury. Mercury is a global environmental pollutant. Its forms can bioaccumulate especially in fish and enter the food chain. Its minimal risk level is at 0.2 $mg/m^3$ and permissible exposure limit is 0.05 $mg/m^3$ . [30] Symptoms of mercury contamination are severe effects to the nervous system with developmental issues that include cerebral palsy-like signs with involvement of the visual, sensory, and auditory systems, tingling around lips, mouth, fingers, and toes, vision and hearing loss. [31]

There had been tremendous cases of mercury poisoning since the Minimata incident. Chemical and manufacturing facilities in Japan in the 1950's contaminated the fishes in Minimata Bay, Japan. Thousands of cases of mercury poisoning had been documented since then around the world. In Iraq alone, there were about 40,000 cases when some 73,000 tons of wheat and 22,000 tons of barley intended for planting and treated with organic mercurials were made into flour. This irresponsible incident caused about 6500 deaths. [32] Mercury contamination is, sad to say, still ongoing in various continents.

Cadmium: Cadmium (Cd), with an atomic mass of 112.41 amu, has properties very similar to zinc. Since zinc is an essential micronutrient for plants, animals, and humans, cadmium can sometimes enter the food chain and get absorbed by an organism. In humans, it is believed to cause renal failure if there is long-term exposure. High exposure can also lead to lung disease, and bone defects. In animals, it is linked to increased blood pressure and myocardium effects. The average daily intake for human is 0.15 mg from air and 1.0 mg from water. Smoking a packet of 20 cigarettes can lead to the inhalation of 2 - 4 mg of cadmium, but levels may vary widely. [33]

Cadmium is produced as a by-product of zinc production. This metal is used in nickel/cadmium batteries, coatings, pigments, and stabilizers for PVC, in alloys, and electronic compounds. It is present as an impurity in several products, like phosphate fertilizers, detergents, and refined petroleum products. Cadmium contamination showed up among workers of Huizhou PP Battery Factory in Hong Kong where there were about 3000 workers affected. This incidence affirmed what researchers had observed on cadmium exposure that once in the body, it will take 7 to 30 years to get the toxins flushed out. [34]

Antimony: We are always exposed to antimony (Sb from Stibium) because this element with an atomic mass of 121.76 amu is found in most paper products and rubber. This metal can also be found in batteries, pigments, plastics, and ceramics. Antimony is a very valuable component in alloy making because of its strength. When exposed to high concentration of antimony, organisms are observed to exhibit nausea, vomiting, and diarrhea. It is a suspected carcinogen. Short-term exposure by inhalation in humans results in effects on the skin and the eyes. Long-term exposure can lead to inflammation of the lungs, chronic bronchitis, and chronic emphysema. [35] The Environmental Protection Agency (EPA) has established the Reference Concentration (RfC) of antimony to 0.0002 mg/m $^3$ . [36] This RfC measure was based on the effects of contamination on rats. Exposure greater than the RfC value has the potential for adverse effects to increase.

Copper: Copper (Cu from Cuprum), a metallic element with an atomic mass of 63.55 amu is essential to plant, animal, and human lives. In high dosage, it may cause anemia, and liver and kidney disorders in humans. It is mostly found in air, food, fungicides, and drinking water because of copper pipes. This also comes from additives that prevent algal growth. EPA requires that the copper level in drinking water be less than 1.3 mg/L. [37] The recommended daily allowance (RDA) in our diets should not be more than 900 mg/day and the Occupational Safety and Health Administration (OSHA) requires the amount of copper not exceed 0.1 mg/m $^3$ in air and 1.0 mg/m $^3$ for copper dusts. [38]

Copper contamination of various bodies of water in the United States began a long time ago. Mining was such an invaluable way for the country's economy to grow and studies done showed water reservoirs flooded with mine workings. Lakes and rivers in Northern parts of California were analyzed in 1987 and copper and zinc concentration particularly coming from the Penn Mine to the Mokelumne River reached to about 1,000 ppm. [39]

Nickel: Nickel (Ni), with atomic mass 58.69 amu, is released as dust in refineries, and is very useful in metallurgical processes. It is an electrical component in Ni-Cd batteries. It is naturally occurring in rivers, lakes, and in plants and animals. Nickel is needed in the human body in very small amount but when taken orally in excessive dosages, it becomes acutely toxic. Reproductive and developmental effects in humans are at 0.13 to 0.20 mg/m $^3$ . [40] Short-term exposure is not that dangerous but long-term exposure can cause decreased body weight, heart and liver damage, and skin irritation.

**Solution Concentration**

Solutions have two parts, the solute and the solvent. We are most familiar with solutions in which a solid is dissolved in a liquid but there are as many types of solutions as there are different combinations of solid, liquid, and gas. We have solid, liquid, and gaseous solutions. A clear example of a solid solution is an alloy, whereas we know that the atmosphere is a good example of a gaseous solution. The mixture of vinegar and water is a liquid solution.

The concentration of a solution is defined as the amount of solute present in a given amount of solvent. This concept is a constant part of our daily experiences. Making coffee or tea, preparing beverages, adding antifreeze to automobiles, or mixing pesticides in the soil we use for gardening apply the principle of solution concentration. This is seen even in simple cooking. It is affected by changing the amount of either the solute or the solvent. There are different ways to describe the amount of solute in a given solvent. We use the terms dilute or concentrated but these only give us a rough qualitative idea of concentration.

Quantitative description is found more effective in describing solution concentration. Because solutions can have varying composition, the relative amounts of substances must be specified. There are some ways we can express solution concentration quantitatively; and these are: mass percent, mole fraction, molarity, and molality.

## Strategies and Classroom Activities

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**Day 1 to Day 5: Photosynthesis Discussion and Making "Starch Pictures" (This is a re-creation of the original observation by Sach's and the whole activity is borrowed from "Energy Plants and Man.")**

*Objectives:*

The fundamental goals of this activity are for students to explain fully what actually occurs in plant leaves as a result of photosynthesis and to provide a visual evidence of light energy transforming to chemical energy.

Photosynthesis will be taught for four days. I will start this lesson with a lab activity on "Starch Pictures." This activity will provide opportunities for my students to observe and examine how water, carbon dioxide, and light produce starch. Making starch pictures uses the principle of developing prints in photography where a piece of photographic paper is illuminated through a negative.

Each of my biology and chemistry classes will be divided into eight (8) groups with three (3) students in each. All groups will perform the activity following lab safety procedures strictly. Each group member will take a specific role, a facilitator, a recorder, and a reporter.

*Materials:*

Geranium plants, 80% methanol, Iodine solution (0.2 g iodine and 5 g KI in 100 mL of water), 100-watt lamp/slide projector, lens, 2 pieces of 3" x 3" glass plates, 5% sodium bicarbonate, black cloth.

*Procedure:*

1. Prepare the geranium plant. Choose plants with leaves that are about 3 inches in length and in width.
2. Keep the plant in the dark for 48 hours.
3. Make the starch picture. Two sets of groups will make starch pictures following two distinct procedures. The first 3 groups will create pictures of good quality by obscuring a part of the leaf with a photographic negative, and illuminating overnight with a 100-watt lamp, at a one-foot distance through a trough of water to filter out heat. The second set of groups will use slide projectors and lenses. Here, they will hold the leaf and a black cloth soaked in bicarbonate solution, in between 2 glass plates, with the lower part of the leaf petiole slightly touching a bowl of water that serves as the base for the set-up.
4. Remove the chlorophyll. This is done by dipping the leaves briefly in near-boiling water. Transfer the leaf to a beaker containing warm methanol. Heat carefully over a hot plate and in a fume hood for safety. It takes about 15 minutes for the chlorophyll to leach out from the leaf. After all chlorophyll has leached out, rinse the leaf well with water and iodine solution.

The activity should be completed after two days. The third to the fifth day will be scheduled for group discussions, analysis, and presentations.

After the lesson is completed, I will use my own form of evaluation, the "Alien Oral Quiz." I will take the role of an alien, and because I came from another planet, I will expect comprehensive answers for all my queries. The following are some of the questions I will ask:

1. Why did you keep the geranium plant in the dark for 48 hours? What do you think will happen if you kept it in the dark for less or more than 48 hours?
2. What actually happened in the leaf while the plant was in the dark?
3. Why did you use methanol for bleaching?
4. Why is iodine solution used?
5. Why did you illuminate only a part of the leaf?
6. What is the purpose of the bicarbonate solution?
7. What are those "pictures" formed?

To strengthen the concepts formed from the activity, I will show the last five slides of the power point presentation on "Starch Pictures." This will also be done in the event that there are no clear pictures of starch formed.

Class discussions following the lab will be enriched by the integration of green chemistry concepts on photosynthesis. I will utilize the power point presentation given by Dr. Gary Brudvig, [41] so my students can compare and contrast natural and artificial photosynthesis. I will also take this opportunity to explain the ongoing scientific researches that look at photosynthesis as a possible energy resource in the future.

**Day 6 to Day 10: Bioaccumulation Game and Discussions on Pesticides**

Games are very effective tools that teachers can use to teach a concept. It is participatory so that even difficult students put down their defenses and anxieties. I use games also for the purpose of building motivation and confidence among my students. I like translating lessons into simple games because it helps sustain interest and is always a welcome break from the routine of lab activities and class discussions.

*Objectives:*

At the end of the 45-minute activity, students should be able to discuss the process of bioaccumulation, and identify threats and dangers to ocean communities, including humans.

*Materials:*

3 bags of m & m candies, 3 big green hoops (diameter of 40 cm), 2 small blue hoops (diameter of 20 cm), paper plates, plastic cups, computer with speakers, labels, post-it nametags, large post-it papers, and markers.

*Rules of the Game:*

In this bioaccumulation game, students will role-play the organisms that make up the food chain in the Arctic Ocean. A great part of their participation grade is their aquatic-like costumes.

In this activity, the classroom will be the Arctic Ocean. All students will be assigned to play different roles.

These are as follows: 15 students are zooplankton (copepods), 8 are arctic cod, 2 are seabirds, 1is a whale, another one is a ringed seal, 2 are polar bears, and the last 1 will represent a human being. 180 pieces (30 each of blue, orange, brown, green, red, and yellow) of m & m candies will be the photosynthetic phytoplankton, and these will be scattered in the playing ground. Each organism holds a cup, serving as its stomach. Five hoops are placed inside the ocean ecosystem, the 3 bigger hoops are the protective covers for copepods, and the two smaller ones will protect the arctic cod. Each bigger hoop can only accommodate 2 copepods, and the smaller hoop can only hold one cod. The whole classroom is the playing area and hunting ground for all organisms. While these organisms play and hunt, they have to "swim" around. There will be 3 music-directed hunting seasons. Organism in the ocean should observe the following rules:

1. The first season will have the zooplankton only. While the background music plays, all zooplankton (copepods) will roam around and hunt for food. (The background music is an environment song).
2. Zooplankton (copepods) feed on m & m's (photosynthetic phytoplankton) only. All colors, except red, can be eaten.
3. When the music stops, the predators attack. Arctic cod will attack by tagging the copepods. The cod can take cover by swimming into the hoops. Any copepod tagged by a cod is considered "eaten" and will transfer all of its plankton contents into the cod's cup. The cod that are not tagged will play in the next hunting season and they continue eating the plankton. One bigger hoop is removed from the playing/hunting area.
4. The background music will again play, and when it stops, another set of predators will come into the area. They include the ringed seal, a whale, and two sea birds. They will swim after the cod, and the cod will look for cover. Some will be eaten; some will live longer because they are inside the protective cover. Organisms that are not tagged continue to hunt for food. One big and one small hoop are removed. At this point, there will only be two protective covers left, a big and a small hoop.
5. The third hunting season begins, and the music plays. This time, the music will play longer and the music will stop suddenly and the bigger predators come in, they are the 2 polar bears, and a human being. Predators will tag their prey, and at the count of 5, I will say, "stop."
6. All organisms will stop moving.

After the activity, I will ask the students to make a diagram of the food chain they have created. Using arrows, they will identify which organisms are on the first, the second, the third, and the fourth level. They will then count the total number of each colored m & m an organism has in its cup. They will count the red candies left in each of the cups. This time, when each count is listed on the board, I will inform the students that the red candy contained contaminants.

From the 7 th to the 9th day, I will be discussing lessons learned from the game. To reinforce the concept of bioaccumulation, I will be showing the DDT video, [42] and the Paul Anastas' Running the Numbers [43] power point presentation. During these discussions, I will integrate one of the principles of Green Chemistry, that, in meeting people's needs, we have to learn how to use/design sustainable products. During this time, I will assign them to look for articles and resources that will prepare them for a class debate on "The Creating Powers of Chemistry." All classes will be divided into two groups, representing the pro's and the con's, with a speaker for each group. The class debate will take place on the 10 th day of implementing the curriculum unit.

**Day 11 to Day 20: Case Studies, Activities on Measurement and Solution Concentration and Culminating Activity**

All classes will be divided into 6 groups, with 5 members in each group. Each group will choose a case study.

The case studies involved places in Chicago and some places in the Midwest that were documented to have been contaminated with heavy metals. The first five case studies are taken from the EPA Region 5 Superfund Sites, [44] and the last one is a case study from the state of California.

1. Cottage Grove Landfill, Chicago, Illinois, August, 1995
2. Pullman Factory, Chicago, Illinois, September 1995
3. Cosden Oil and Chemical Company, Chicago, Illinois, October 1996
4. Johnson Iron Industries, Charlotte, Michigan, January, 1995
5. Bennette's Dump Site, Bloomington, Indiana, November, 2005
6. Chromium Contamination in Glendale, California, November, 2000 [45]

Each group will read and study the cases assigned to them. As they analyze the data presented by the cases, they should be guided by the questions below:

1. Is the contaminant in its pure elemental or compound form?
2. Is it soluble or insoluble in water? Why did you say so?
3. From the rule, "Like dissolves like," how will you classify the contaminant, is it polar or nonpolar?
4. If the contaminant is polar/nonpolar, how will you rate its toxicity effects on humans and other living organisms?
5. Compare and contrast the heavy metal contamination among the organisms discussed in your assigned case.
6. Make a diagram of the food chain suggested by your case study and list the amount of contamination for each organism in the chain.

All groups will also be required to submit an analysis chart shown below:

(table is available in print form)

Table 1: Analysis Chart of Heavy Metal Contaminants and Toxicity Effects

When my students are done with studying and analyzing data, and after they have presented the concentration of contamination, I will start integrating units of measurement. I will also use this opportunity to discuss dimensional analysis.

*Discussion of Solution Concentration and Presentation of Cases by Groups*

I am pretty sure a majority of my students will also ask me about the units for solution concentration used in the case studies. Again, I will grab this chance and lead them to the discussion of solution concentration. This is the time that I will give my students an in-depth instruction on solution concentration. This teaching will take the last four days prior to the culminating activity.

The culminating activity in my curriculum unit is a power point presentation on the assigned case by each group. The presentation, which will take place on the 20 th day of the implementation of the unit, should include the following:

1. History of the place where the case took place
2. Geographical location of the landfill
3. Analysis chart on the assigned case

4. Properties and characteristics of the elements present in the contaminants
5. Common compounds the element is found in
6. Toxicity levels of contamination

## Implementing District Standards

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State Goal 11: Understand the processes of scientific inquiry and technological design to investigate questions, conduct experiments and solve problems.

The inquiry process prepares learners to engage in science and apply methods of technological design. This understanding will enable students to pose questions, use models to enhance understanding, make predictions, gather and work with data, use appropriate measurement methods, analyze results, draw conclusions based on evidence, communicate their methods and results, and think about the implications of scientific research and technological problem solving.

State Goal 12: Understand the fundamental concepts, principles and interconnections of the life, physical and earth/space sciences.

This goal is comprised of key concepts and principles in the life, physical and earth/space sciences that have considerable explanatory and predictive power for scientists and non-scientists alike. These ideas have been thoroughly studied and have stood the test of time. Knowing and being able to apply these concepts, principles and processes help students understand what they observe in nature and through scientific experimentation. A working knowledge of these concepts and principles allows students to relate new subject matter to material previously learned and to create deeper and more meaningful levels of understanding.

State Goal 13: Understand the relationships among science, technology and society in historical and contemporary contexts.

Understanding the nature and practices of science such as ensuring the validity and replicability of results, building upon the work of others and recognizing risks involved in experimentation gives learners a useful sense of the scientific enterprise. In addition, the relationships among science, technology and society give humans the ability to change and improve their surroundings. Learners who understand this relationship will be able to appreciate the efforts and effects of scientific discovery and applications of technology on their own lives and on the society in which we live.

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