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Fostering Connections: The Elements of Nano

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Objective

> The real voyage of discovery consists not in seeking new landscapes, but in having new eyes.
> ~Marcel Proust

The focus of this unit is to heighten awareness of the use of polymers in the world so students can make informed choices about the world around them. In the context of a day in the life of a high school student, and exploration of polymers in the world students will then explore how the making and use of polymers affect the natural world. Students will investigate polymers as structural components, energy sources and potential hazards. Finally students will be able to explain the short and long-term impacts of taking fossil fuels from the earth.

Academic Setting

The proposed unit will be written primarily for teachers of Freshman Science but can be modified for other levels of chemistry, biology and environmental science. This unit assumes students have a working knowledge of the metric system, atoms and elements, and the properties of elements. Lessons were formatted with an inquiry approach that utilizes Common Core standards.

Introduction

Students will often say something is large, or small without the understanding that size is relative to what an object is compared to. To help with the understanding of the size of an atom, comparisons are often employed. If an atom were the size of a basketball, then a dime of atoms would be the size of the entire planet, or if an apple were as big as the Earth, then each of the Earth's atoms would be the size of an apple. An atom is mostly empty space; therefore if the sun were a nucleus of an atom (protons and neutrons) then Mars would be the closest electron. Size is important to understand when polymers are described as large molecules. When atoms are bonded together they make molecules. If small molecules are repeatedly bonded together into large chains molecules then the small molecule is called a monomer and the large chain a polymer. A monomer is like a crystal of sugar and a polymer is like a bowl of spaghetti (starch). One long noodle would make a polymer chain of monomers, like a bowl of spaghetti, and this molecule would have specific properties. Spaghetti is a good analogy because you can think of spaghetti that is heated and cooked, soft and pliable and as the dry, hard, straight chains. Polymers are much the same. As more and more monomers become larger and more condensed polymers, the molecule becomes denser and more brittle, thus the properties change when heat is applied and molecules are lost.

Carbon

Carbon's atomic number is 6, with 2 electrons in the first orbit around the nucleus; the remaining 4 occupy a second orbit. Carbon is likely to want to share electrons because of the four open spaces needed to form an octet, full valence shell. Carbon is very "friendly" with other elements especially hydrogen, oxygen and nitrogen and is neither electronegative nor electropositive. Large organic molecules like carbohydrates, lipids and proteins are made combinations of these molecules and along nucleic acids are the building blocks of all living things.

Carbon also likes to bond to itself and is known to form double and triple bonds, which contribute to unique properties. This means that carbon can bond indefinitely, allowing for huge molecules with high molecular mass that can be arranged in a countless number of ways. At Penn State, Dr. Patricia A. Bianconi reasoned that man could make diamonds from charcoal if the right conditions were met. With all the ways carbon can bond, if enough heat and pressure were applied highly concentrated molecules with high molecular weight can be formed. Carbon can become a diamond. Diamonds are the hardest of all substances and are useful in many ways. Unlike diamonds, hydrocarbon polymers can combust and therefore provide heat and energy when combusted. Combustion includes the addition of oxygen generates heat and light in the form of a flame. The byproducts of combustion of hydrocarbons are carbon dioxide and water, which are, unfortunately, pollutants when there is too much.

Polymers

'Poly' means many and 'mer' means 'units'. A polymer is made up of many 'mer' units linked together in long chains. Polymers can be very large molecules and possess a variety of properties depending on the extent to which they have been processed and what they are made from. Most polymers are former hydrocarbons or derivatives of hydrocarbons.

Natural polymers such as silk, cotton, starches (spaghetti is a polymer!) and even sand are large molecules made from monomers of carbon, hydrogen and oxygen. Carbon has four bonding sites and bonds to itself with single, double and triple bonds. Carbon(C) atomic number 6, Hydrogen, (H), atomic number 1, and Oxygen (O), atomic number 8, form two of the four macromolecules that make up all of life: carbohydrates (sugars) and lipids (fats). When Nitrogen (N) atomic number 7 is added then protein and nucleic acids are formed. Carbohydrates are the sugars, starch and the cellulose in a plant; they are made up of long chains of the monomer glucose. Carbohydrates provide energy for the cell. Lipids are long hydrocarbon chains they provide protection and selection for the cell. Proteins are long chains of polypeptides. Polypeptides are made up of long chains of amino acids and other elements. These macromolecules are the building blocks of all living things and are cycled throughout the Earth. Seventy eight percent of our atmosphere is nitrogen, 21% oxygen and most of the 1 % left is carbon, water vapor and other gases. The waters of the Earth are hydrogen, and oxygen with a large supply of carbon and our land is made up of decaying matter and minerals.

The simplest molecule in the decay of living thing is a hydrocarbon. This molecule is a chain of hydrogen and carbon atoms and is classified by the type of bond it contains: single, double or triple. Hydrocarbons are organic molecules, polymers that occur in nature. They make up fossil fuels, are in all plants and animals and form pigments that make the green vegetable green and orange vegetables orange. The largest percentage of natural rubber is a hydrocarbon polymer that has become one of the most manipulated structures to date.

Synthetic polymers are often derived from organic polymers. Synthetic polymers are difficult to avoid in today's world. As technology advances polymers become more complex and much more diverse. Polymer products have revolutionized our lives. Most man-made polymers are some form of hydrocarbon or hydrocarbon derivative. The term plastic refers to polymers that are synthesized from fossil fuels. All plastics are polymers but not all polymers are plastic. Some artificial polymers can stick very well to materials such as metals and are used coatings. Polymers can be molded, stretched, shaped, reformulated and made into just about everything we use everyday. A polymer alone or in combination with other materials has a global market reach in everyday items.

Polymers in everyday life

Open a door or even a window and you will see all kinds of polymers. Inside every living thing is a very complex polymer called DNA that carries the blueprint to recreate that living organism. Plants contain cellulose, an excellent fiber built out of polysaccharides that make up cotton, plant stems, wood and paper. Organic polymers like cellulose were used to make some of the first the first synthetic polymers. Starch is another organic polymer found in corn, wheat and potatoes that is also made of the monomer glucose and used as the basis of biologically degradable polymer mixtures. Starch is used to make environmentally friendly 'packaging peanuts" which dissolve in water. Starch can be broken down by another polymer, enzymes, into glucose so the cell's mitochondria can use it for energy. Enzymes have found a place in coating synthetic polymers to reduce infection when placed inside the body. This field of research is new and upcoming and holds promise for the making of artificial organs.

What makes these three polymers different is how the glucose molecules are put together in the polymer chain. The difference between starch & cellulose is where the OH molecule is located on the glucose ring. Alpha glucose, will make starch for energy, beta-glucose will make cellulose for strength. Enzymes are proteins made by protein synthesis inside of cells, starch & cellulose are made by dehydrations synthesis where a water molecule is lost and the glucose molecules are joined, a condensation reaction. If all of the water were removed from that bowl of spaghetti, what would be left would be hard, brittle noodles, starch, with different properties but still the same molecule. By studying the structures of these polymer molecules and how they are formed in nature, man has learned to make synthetic polymers that we find around us everyday.

Polymer Make up

All compounds are made up of two or more different types of atoms. For example H_2 (hydrogen gas) is a molecule but H_2O is a compound because both hydrogen and oxygen are present. H_2O is also a molecule because how hydrogen and oxygen bond. Polymers are long chains of molecules. Polymers are very large molecules and can be branched or cross-linked. There are two major types of polymers; natural, as in found in nature, and synthetic, formulated by man. Natural polymers are complex carbohydrates such as cellulose, glycogen, cotton, wool, silk and starch. Natural polymers have enzymes to break them down. Enzymes lower the activation energy needed for natural substances to breakdown, thereby increasing decomposition time. And there are established pathways that recycle each of the components. Natural polymers were the inspiration for man-made polymers.

The first polymers were made by a condensation reaction called dehydration synthesis. In this condensation reaction, losing a water molecule combines "mers" and chain is formed. In the making of polymers a series of reactions called condensation reactions take place and monomers or monomer chains are added to one another to form longer chains. Other names for these reactions are 'step-growth polymerization' or 'condensation polymerization'. If there were two monomers labeled 'A' and 'B' then these reactions can form A-A and B-B, polymers as well as A-B polymers. A small molecule is usually liberated.

This type of reaction is used as a basis for the making of many important polymers. Only the number of monomers that are available to bond limits this process. When other elements were added, the range of polymerization expanded and the properties of the polymers became more diverse. These 'copolymers' were compressed to become tougher, harder, and more elastic, and have greater strength. Still these did not compare with natural polymers where one identical monomer unit was added at a time to the ends of polymer chains and the process of breaking down and making new compounds has evolved over eons of time. New techniques were developed in the making of synthetic polymers and a four-step process is now used in the synthesis of most polymers.

Types of Polymers

There are two major types of polymers: ones that can be heated and remolded (thermoplastics) and those that cannot (thermosets). Charles Goodyear found that if he added sulfur and white lead and heat to natural rubber he could make cross links and the rubber would not melt when it was hot outside nor become hard when the temperature dropped; thus vulcanized rubber was born. This proved to be very useful for making tires, and taught scientists to heat natural polymers and add chemical cross-links to make them stronger and more durable. Suddenly thermosets were born. Thermoset polymers are molded and shaped before heating and after heating retain their shape. Thermosets are cured (or hardened) in a process known as vulcanization, which produces an irreversible chemical reaction. This changes the material forever, making a stable, chemical and thermal resistant durable product. While thermosets have their uses, however, they are not easily broken down and therefore pose environmental issues. What happens to the tire when it is no longer useful for a car to ride on?

In search of a more pliable material, chemists found they could heat natural polymers and mold them without adding chemicals to crosslink and change them permanently. These became known as thermoplastics, the change in these products is purely physical and with reapplication of heat, reversible. This makes recycling of thermoplastics a possibility until the material begins to degrade. While thermoplastics do service humans, they will eventually end up in landfills and are not completely recyclable.

Scientists continue to work with heat and rubber and other natural polymers to create an "in-between" type of polymer. This is known as a thermoplastic elastomer. This is a blended material that has two phases, called co-polymers - one that is pliable (ionomers) and the other made of more than one type of monomer is called a block co-polymer. Ionomers have a few ionic groups attached to them that "tie up" the polymer backbone chains, like a cross-link would. If heated these ionic clusters will break up and can be reprocessed and recycler like natural polymers. Cool them and the ionic cluster form again and the material acts like a cross link again. Elastomers are a type of thermoplastic that retain their shape after being deformed, both natural and synthetic rubber make good raw materials tires for this reason.

Block copolymers are made out of one, two, or more co-monomers. The different monomer "blocks" alternate in a series helping to bond making high-temperature resilience and low-temperature flexibility. Polyurethane, shoe soles and tire treads are made from block copolymers. The next generation Nano devices could be based on these copolymers as we search for materials that are better insulators and photoresists. Photoresists are polymeric coatings that are designed to change properties upon exposure to light and are used to print the patterns of conductors on circuit boards and the tiny transistors on microchips. Our next-generation computers may come from polymer modification chemistry. Polymer derivatives are being explored everyday; hopefully scientists will continue to look to nature for better ways to recycle these materials as well.

One process called cross-linking makes polymers stronger, flexible, and more durable and keeps natural polymers from rotting. This may be one link in the recycling process. Tanning is an example of a cross-linking process that creates a usable but totally recyclable product This is the process of making animal skin (rawhide) into leather by adding brains, oak bark or chrome salts to alter the protein structure of the skin causing the crosslinks that make the skin more pliable. Add a little friction (heat) and the skin becomes soft, resilient, and supple. Scientists are looking at this process to make better polymers for clothing and to make products more recyclable.

Addition of inorganic particles to polymers can augment the strength, conductivity, optical and catalytic activity of polymers. Owen Webster in his article Living Polymerization Methods states that "Possibly the most useful physical property of polymers is their low density versus strength." He tells of the "nonstop circumnavigation of the world by a plastic airplane on one tank of gas and by the construction of an airplane light enough to fly more than 110 km nonstop under human pedal power." As man continues to explore the diverse natural world, he learns to apply the principals and processes found in nature to make better products for humans and for the Earth. The problem may be in the products we have already created and our ability to break them back into useful elements that will become future products.

Plastics

As scientists have learned to heat and add molecules to make up the world of plastics as we know it. The numbering of polymers and efforts to recycle, reuse, reclaim plastics in our world has been due to the public outcry for curtail the volume of man-made products that alter ecosystems in the natural world. Humans dredge millions of gallons of fossil fuels from underneath the earth's surface to make their lives easier. These fossil fuels have been refined into useful human products. Fuel sources for airplanes, cars, boats and our homes have been refined in huge factories for our comfort. The byproducts of these processes are used to cover our roads (asphalt) and now just about everything we use as plastics have been developed from the last end products of this refining process.

Part of the science behind the widespread use of these copolymers is their relatively narrow molecular weight distribution and low gel content. Low gel content is a required property because gel molecules often tangle, causing processing and clarity issues. Low gel content is required for good clarity and process ability, especially for end-use applications such as film, while narrow molecular weight distribution allows for transparency. Also, low gel content also is important in multi-layer structures where gels can cause dimpling and other imperfections. Next time you squeeze that perfect portion of toothpaste on your toothbrush or cover your fries with ketchup, you may be holding an award-winning packaging product in your hands.

The polymers are also used in single or multiple layers for a number of applications such as part of the structure for toothpaste tubes and the small foil condiment pouches used at restaurants and fast-food outlets. Juice boxes and dry food packaging, among many other applications, also often contain the polymers.

Artificial (synthetic) polymers include plastics like Low-density polyethylene (LDPE) and High-density polyethylene (HDPE) used for plastic bags, food packaging, and other plastic containers. Styrofoam, plastic wrap and fabric fibers such as nylon, Rayon and Dacron (polyester) are all synthetic polymers. Also, coating materials such as Formica and Teflon, as well as hard plastics like PVC pipe and the Kevlar that is used for bulletproof vests. To show how well man made polymers have been integrated into our lives, a student will examine what she encounters in a typical morning getting ready for school and point out the polymers she comes in contact with.

Polly's Morning Discovery

Polly is an imaginary teen. She wakes to the sound to her alarm clock (possibly made of polystyrene –a hard low-cost plastic which can be molded into a shape). The sheets and blankets on her bed are most likely made from a combination of a natural polymer (cotton) and polyester like Dacron. Polly gets out of bed her feet landing on a soft carpet. This polymer carpet can be made from a myriad of polymer fibers. This industry is continually looking for new ways to make carpet softer, easier to clean, and aesthetically pleasing to the buyer. Off to the bathroom to brush her teeth Polly finds her toothbrush, made of predominantly nylon, and toothpaste that contains polyethylene glycol, a low–toxicity and low–hazard risk polymer and maybe carboxymethyl cellulose, a polymer thickener, in the medicine cabinet. The cabinet is made of pressed wood fiber (cellulose polymer). As she reaches for the shower door she realizes that it is no longer made from glass but is a clear plastic (acrylic), and the shower bed is also a high–density polymer resin (H.D.P.). In the shower the shampoo and liquid soap (Polyquaternium–10, Polyquaternium–7, Polyquaternium–11, and/or Guar hydroxypropyltrimonium chloride. and silicones that may also be included dimethicone, amodimethicone, cyclopentasiloxane, cyclomethicone, dimethicone copolyols, or dimethiconol) bottles are marked with the HDPE recycling symbol. There is even a plastic squeegee with a note from Mom to wipe down the new shower and spray with a transparent polymer coating (TPC) surface protector. Drying off with a towel (rayon) Polly returns to her room (walking on tile floors made of polymers (PVC) and wood floors (Cellulose) coated with polymers (polyurethane) to put on her clothes, mostly cottons blended with polymer (polyester) for better stretch, resistance to soiling and durability.

Polly heads to the kitchen to make a lunch for school and used a plastic wrap (polyvinylidene chloride) to wrap her sandwich, plastic baggies (LDPE) for snacks and a plastic container (polystyrene) for her muffin. Books & papers are also made of cellulose Polly realizes as she packs them into her book bag. Pouring hot water over a teabag in her Styrofoam cup, she slips into her Crocs (Croclite), puts in her headphones and heads to the bus stop. From music she listens to the seat on the bus and in the classroom, Polly can trace the manufacturing of each product back to a natural or man-made polymer molecule. So, "what's all the fuss about?" she wonders as she walks into her first period class.

The Concern

The "fuss" isn't about polymer use – the fuss is about the toll polymers and their manufacturing process is taking on the earth. Many polymers take years to break down and their use (or overuse) has caused irreversible changes in ecosystems. Polymers seem to be designed to throw away but their physical make up suggests they will last forever.

Classification

In an effort to categorize and thus encourage recycling polymers from hydrocarbons are stamped with a recycling "triangle' that contains a number identifying the type of plastic. Most people think this triangle means that the plastic is easily recycled. For number 1 type plastics, polyethylene (PET or PETE) use for mouthwash containers, soda bottles, salad dressing containers, plastic food jars and water bottles this is generally true. Number 2-type plastics high-density polyethylene (HDPE) is also accepted at most recycling centers (Milk jugs, snack food containers, laundry detergent containers, shampoo bottles, detergent bottles). Numbers 3-7 aren't so easy to recycle. Number 3 is polyvinyl chloride (PVC), used to make cooking oil bottles, shower curtains, medical tubing, pipes and pipefittings. Number 4 is low-density polyethylene (LDPE). LDPE is often colored and used to make grocery bags, meat and vegetable bags, and sandwich, or storage bags. Plastic wrap and squeezable bottles are also number 4.

Polypropylene (PP) is number 5, this plastic is often found colored or printed on. Examples are yogurt, butter, whipped topping and gelatin containers, plastic tubs for food and syrup bottles. Number 6 is polystyrene (PS), the 'to go' contain plastic is found in a cups, bowls, plates and containers. Egg cartons and packing peanuts are also made from polystyrene. Number 7 plastics are all other plastics and are often mixtures. Some things stamped with the number 7 are baby bottles, cell phones, CD's, fast food beverage containers and sports water bottles. This 'resin code' merely indicates the type of plastic used, thus far it doesn't help in determining how fast a plastic will breakdown or the number of times it can be recycled.

Damage

While the recycling of these polymers is certainly necessary and helpful, currently it has not been enough to stop the alternation of ecosystems. Humans have adversely affected millions of species of insects, fish, animals and plant life by alternating natural products to service our own needs. Our oceans have immense plastic dumps, larger than the state of Texas, that are forever altering the ocean habitat. To meet the environmental challenges posed by plastics, polymer chemists continue to research new methods of recycling, and of using recycled plastic, however most state and local governments don't support recycling because it is not a cost effective endeavor in today's world.

Oceanographers and marine scientists studying the conditions of the ocean have found that plastics that have been dumped into the waters are causing many problems for wild life and ultimately for humans as well. Fish are ending up with more and more plastic pieces in their gut, of course, this provides the fish with no nutrition because their systems cannot breakdown the plastic and can cause a potential blockage. The main concern is that the volume is increasing, causing more and more deaths by obstruction, starvation and ecosystem destruction. Recently, marine scientists troubled by an increase in hard-substrate plastics in ecosystems where it is naturally rare, are collecting more and more evidence against the dumping of plastic in to the ocean. Plastic in the ocean not only increases movement of organic pollutants and alien species but may also increase insect populations. One study found that insect populations of Halobates sericeus increased with the amount of plastic waste in the last four decades. This skimmer insect is a large part of the sunlit ocean ecosystem and serves as both predator and prey. An abundance or a shortage of this insect upsets the natural balance of the ecosystem and could cause a chain reaction of changes in the system that are harmful.

Possible Solutions

The facts are that polymers break down much more slowly than natural materials. This poses a huge problem because most of the polymers we use are made for throwing away. This causes vast amounts of trash that is filling landfills and polluting waterways. Half of all polyester carpet made in the United States is made from recycled plastic (PET) and polystyrene is not recyclable. If people were made aware of these facts, there would be less demand for the products of these polymers and industry would need to develop more sustainable materials. For years beverages only came in glass bottles. Glass doesn't wear out and can be recycled over and over again. If the public only bought drinks in glass bottle and refused the plastic then beverage companies would return to using glass bottles. Some people think if bottle deposit laws were stronger and more prevalent throughout the United States then there would be less litter. Switching back to glass would help reduce the plastic bottle pollution.

Another easy solution to polymer pollution is to return to paper for cups, bowls and plates. Recycled paper for on-the-go foods and beverages would address two problems – what to do with all those tons of office paper and would replace polystyrene. Then maybe 500 years from now only a few Styrofoam cups will be in our landfills and oceans. The best tool we have is education. The recent scare about BPA in plastic water bottle cause the industry to make 'BPA-free' plastic bottles. It is interesting to note that this made a "new" plastic bottle, does that mean other plastics won't migrate into our food and water? While glass may break and metal is heavy and cumbersome, it may be the benefits outweigh the inconvenience when the list of harm caused may extend into other generations. Another solution may be on our horizon, as technology continues to advance, our ability to see different solutions expands.

The Promise of Nano

The new frontier in science is looking at carbon, and other elements' structure at the Nano level because at this level matter behaves differently. A nanoparticle (or nanopowder, nanocluster, nanocrystal) is a microscopic particle with at least one dimension less than 100 nanometers. Nanocomposites are also being experimented with as ways to separate molecules. These composites would help us clean water, soil and even air. Other uses of nanocomposite particles have been suggested for lowering the cost in such processes as the desalination of seawater and fossil fuel production, providing a way to neutralize air pollutants, provide artificial skin for burn victims or deliver medication directly to a specific site within a body. Nanocomposite membranes are a green technology that offers energy-efficiency and a lower cost. This technology hasn't been perfected yet. For example, as a composite is able to become more selective in its ability to filter out specifically the porosity of the filter decreases. Scientists continue to work to produce different types of Nanocomposites to perfect the cleaning of water and air, and are discovering many more way these particles can be of use to mankind and the earth.

The scientific community, in post-DDT times, is looking at possible risks of nanoparticles before their use becomes widely available. DDT (dichlorodiphenyltrichloroethane) is an insecticide that was widely used to control "pests" prior to the environmental movement of the 1960's. This pesticide is a white crystalline solid, which is odorless and very effective at controlling insects, especially the mosquito. In the 1960's Rachel Carson's book *Silent Spring* called the nation's attention to the harm widespread spraying of DDT was having on ecosystems and humans. The controversy was due to the effectiveness DDT had at killing insect populations, which helped reduce the spread of disease, and the long term affects of this chemical on living things. Today's caution is due to past introduction of a seemingly 'nonpolluting' method to address a specific issue, that a few years later became a large concern due to biological uptake. Nano scientists are looking at how to introduce nanoparticles and their implications in the biological, as well as physical world, as well as a how they might move throughout an ecosystem. Learning the ultimate impact in terms of potential aggregation in the future would ensure that we are not just making a larger problem. This science is new, has millions of applications and shows promise for helping clean up the mess we have made with fossil fuels. While there is more research to be done nanoparticles are fast making their way into our world as the future of everything from curing blood disease to filtering microparticle pollution from our air. Nanoparticles have been shown to carry drugs to specific sites in human systems, control cell growth, absorption, location, create a transistor, deliver chemotherapy drugs, clean up tetrachloride pollution, increase battery power, provide a barrier to gases and moisture and UV light. They have also been used to strengthen fibers, kill bacteria, clean water, and fight infection as well as destroy cancer cells without harm to healthy cells. Since the properties change when particles get down to the "nano-size" a nano tube can be very flexible yet 100 times stronger than steel and be a great conductor of electricity. Currently nanoparticles have found use in skin car products reflecting sunlight, tennis balls lasting longer, wrinkle and stain resistant fabrics, healthcare and technology. Most nanoparticles are made by produced by natural phenomena, cooking, internal combustion and industrial and domestic endeavors, unintentionally release nanoparticles. Recently, nanoparticles have been engineered and are fast becoming components of products and of technology. Environmental uses are also being researched, there may soon be a solar 'paint" that suddenly makes solar energy a cheap alternative fuel. Universities throughout the country are beginning to offer courses in Materials Science that help students utilize nano characterization tools and introduce students to high tech imaging and research into this new and exciting field. There is much promise in continued research into Nano particles and their use to help undo some of the harm cause by the use of fossil fuels.

Humans dug deep into the earth to bring fossil fuel to the surface to bring energy and comfort to our complicated new lifestyles. Scientists continue to explore ways to provide energy to the growing number of people that inhabit the earth. It may be that nanotechnology will introduce ways to clean up the pollution in the environment that overuse of polymers has caused. We may not be able to recover the ecosystems that have been destroyed by our waste but at least now there is promise of a technology that works on nature's microscopic scale, and we are cautious, having learned, hopefully, from our mistakes of the past. Perhaps we will be able to live with this wondrous blue planet instead of on it. The hope of Nano is to return, recycle, restore and live and work with nature so that a harmony exists for all.

Lesson plans

LP1 – Engagement (1 period)

To introduce polymers, nanoparticles or anything that is made from matter, students need to have a good concept of the size of particles. A discussion should center on atoms, molecules, compounds and how in the physical world those compounds becomes our "things". Introduce students to variety of things made our of polymers; a piece of cotton, cotton fabric and a cotton-blend fabric would be great to compare to a grain of sugar a blade of grass and a piece of spaghetti (I love spaghetti so I use it a lot!) and compare these to a similar progression in the physical world. An example would be an element such as copper is made into a wire that becomes the conductor of electricity for a telephone. Show the Ted Ed video "*Just how small is an atom?*" Discuss and have students draw analogies (blueberries/grapefruit). Then introduce polymers. Draw ethylene on the board Have students draw a simple molecule like ethylene (C_2H_4) on square of paper (precut of tag board would be best). Have students gather around a desk bringing their molecule, ask students to join their molecules. Have students describe what they get (polyethylene) and how it could come about (condensation, heat and pressure). Show polymer examples in the classroom. (Any plastic, a plant, fabric etc.) Ask students to bring a list of 10 examples of polymers they have at home for homework.

Objectives

- Review composition of matter: atoms, molecules, compounds
- Develop an understanding a size of atoms, molecules compounds
- Introduce monomers, and polymers

Sequence

1. Watch: How small is an atom? *http://ed.ted.com/.* Discuss size of atoms in relation to size of polymers, review atom->molecule->compound. Have students draw analogies.
2. Introduce the students to a variety of different types of polymers. Bring in examples
And have a class discussion about each one.
3. Discuss how these polymers might be used in our everyday lives.
4. Introduce the posed problem/required task– suggest each student bring a list of 10 polymers

they use from the time they get up in the morning until they arrive in class.

LP 2 – Explore (1 period)

Make lists of polymers that students bring in on the board or paper and discuss what they think the source material is for each – categorize polymers into groups (and discuss how each group may have been made and from what raw material. A chart is in Appendix Hand out *Polly's Morning Discovery* . Encourage groups to list polymers in their journals after the first read through. Encourage groups to categorize polymers into raw material groups. Bring the class back together after 30 minutes to view a short video that categorizes polymers into 7 groups and have students take notes, encourage students to view other videos as they complete their homework after school.

Objectives

· To recognize polymers in the world
· To examine the raw materials polymers come from
· To discover the relationship between hydrocarbons, fuel and plastics
· To acknowledge the worlds current dependence on plastics

Sequence

1. Whole group-Review student list of polymers, discuss differences & categorize by similar raw material
2. Handout *Polly's Morning Discovery* – put students in groups of 4 or 5, have them read and discuss. Assign questions for homework. (30 minutes)
3. Whole group – *http://www.containerandpackaging.com/info/plasticology.asp* to show the differences between various types of plastics. Have students note raw materials, and processes used to make each type of plastic. The site has 7 short (& silly) U-tube videos you can encourage the students to revisit for homework.

LP 3 – Research (1 period)

For this lesson book a computer lab or laptop cart so students can explore a website. Introduce students to the site and explain each level. Instruct students to choose one of the polymers from last night's homework to explore through each level of *Macrogalleria* . Allow students to chose but assign them different polymers so that the class has a good variety of exploration. Students should use the worksheet to fill in facts about their polymer. For homework they transfer the facts to a graphic organizer to be used the next day in class.

Objectives

· To do self-guided research on an unexplored topic
· Recognize the connections between every day objects and their source materials
· Discover the process of making polymers from raw materials
· Understand the scope and variety of polymers in our world

Sequence

1. Introduce the students to the Macrogalleria web site (http://pslc.ws/mactest/level1.htm) and allow them time to explore

2. Assign each student a polymer from *Polly's Morning Discovery* to explore

a. Chemical and physical structures of their polymer
b. The chemical and physical properties
c. The process of making the polymer
d. The uses and benefits of the polymer and possible improvements
e. The pros and cons of using the polymer.

3. The students will organize their facts into a graphic organizer

4. Students must have a minimum of 3 citations.

5. Students will return to their groups tomorrow to organize their information into a presentation

LP 4 – Synthesis (1–2 periods)

Computer access and student groups are needed today. Check on student groups as they gather together. They will spend one period organizing the research each has done into a presentation. Instruct students to find a central common theme for all the polymers in the group and make their own graphic organizer. From this organizer they choose how to present the material. Each student will make 2 slides for a power point– one with their information and the second with their resources. The last slide poses a question the group would like to ask the class about the future of their polymers. Teacher would monitor that students don't get too far off topic but allow them to go with whatever idea they may present. The hope is that students will begin to question the use of plastics and look towards more sustainable products. The central area of the graphic organizer would likely be fossil fuels or hydrocarbons and the areas around would list the polymers the groups investigated and their uses, pros &cons

Objectives

- Enhance inquiry skills
- To allow students to follow through and develop ideas
- Design a group presentation to present ideas
- To sharpen skills on polymers structure, properties, use and future.
- Formulate a question after research and analysis

Sequence

1. Student groups will compare their graphic organizers and create a power point presentation (12-15 slides) that presents what they have learned about polymers

2. The last slide is a question– they would like answered after their exploration

3. Student questions should be listed for all to see– the class may chose one to explore as a final project for this unit. (Ideally, this would a question about recycling, reusing or even remaking of plastics to make them more sustainable).

LP 4 – Experimentation (2–4 periods)

This lesson is a state embedded task that can be found at *http://www.sde.ct.gov/sde/cwp/view.asp?A=2618&Q=320892*

Polymers – Strand II –Chemical Structures & Properties – student and teacher materials are found there. Teachers will need to gather different types of plastic bags, washers, tape and paper clips. All components of the task are outlined on the website in both teacher and student worksheets

Objectives

- To explore chemical technologies present both risks and benefits to the health and well being of humans, plants and animals.
- Identify questions that can be answered through scientific investigation.
- Formulate a testable hypothesis and demonstrate logical connections between the scientific concepts guiding the hypothesis and the design of the experiment.
- Design and conduct appropriate types of scientific investigations to answer different questions.
- Use appropriate tools and techniques to make observations and gather data.
- Assess the reliability of the data that was generated in the investigation.
- Articulate conclusions and explanations based on research data, and assess results based on the design of an investigation.

Sequence

1. Provide students with plastic bags that have a label on them and demonstrate a way to test the strength of a plastic bag using the materials given for the experiment.
2. Students will design and write an experiment to test the strength of various plastic bags
3. After the experiment is tested, students analyze the data and draw conclusion based on whatever research they need to do to write a conclusion
4. In part II the students assess the validity of the information used in their research and determine it's accuracy using the website provided by the state.

LP 5 – Enrichment

Depending on how much time or to what level a class can be taken LP 5-7 offer further exploration and connection between polymers and everyday life. In LP 5 students watch a movie that is highly recommended when teaching polymers. The film is a documentary that is entertaining and provides new insight into polymers, pollution and water. LP 6 explores common myths about recycling and allows students to examine the facts about what actually happens to our trash. Students inform each other about the world of trash collection. And LP 7 *CONSIDER INSIGHT* investigates the future of plastics in current nanotechnology as products begin to infiltrate the shelves in the stores where we shop. Ideally, all three of these plans could follow the State–embedded task and students would really get to know the connections between polymers and their lives.

In LP 5 students will watch the movie *Tapped* , filling in the question sheet as the movie plays. The film is powerful, introduces new ideas and students can examine it's claims for credibility. A worksheet is in the Methods & Materials Appendix A.

Objectives

To examine the role of bottled water in our lives

To observe the place petroleum has in the manufacture of plastic.

To look at large companies and how they diversify

LP 6 – Enrichment

Students are encouraged to be a *Mythbuster* ! Student pairs pick one of the *5 Myths of Recycling* found at *http://www.ilsr.org/the-;five–most–dangerous–myths–about–recycling* / and research the facts.

Student pairs present both sides of the argument in a debate with each other.

Students are responsible for one page typed of fact-based information, or 10 power point slides, or 2-challenging fact posters or a 5-minute video.

All must have a minimum of 3 citations of credible websites or books. Debates will be presented in class and the winner of each debate adds 20 points to their grade.

LP 7 – Enrichment

The Promise of Nano technology– CONSIDER INSIGHT project

Students chose an aspect of Nano technology and research both idea, and the product must find a university, organization or company working with this product. The object is for the student to contact the researchers of their nanotechnology and get a written or oral interview response to six well-thought-out questions and then teaches the idea to the class.

Choose an idea to explore in the field of Nanotechnology

Obtain 12 questions that explore your idea

Narrow down question to 6 that are the most interesting to you.

Search for universities/businesses/ companies that have an interest in your idea

Invest in stamps & envelopes

Determine which 3-5 companies will be likely to grant you an interview

Envision your interview– then write the letter that will get you the interview

Read and respond to company letters

Interview contact

Note (or record if permission is granted) all answers

Suggest follow up (visit/interview?)

Interest them in you– sell yourself!

Gather facts/ answers / information into a presentation (ppt or poster) for the class

Hold a discussion that will review what you have learned and help others learn

Test your classmate's knowledge of your project with an assessment

Methods & Materials

Activity 1 –

The size of atoms- drawing paper. Have students write out the number of zeros from meter to nanometer to help them get a sense of the size of an atom. Then have them try to find analogies to help relate better to the

comparison of the size of an atom and the size of a polymer. Examples can be found:
http://www.ualberta.ca/~urban/Samples/Peas.htm- Green Pea Analogy

http://www.newton.dep.anl.gov/askasci/phy99/phy99394.htm - basketball/atom-dime/earth

http://www.conservapedia.com/Atom - fly in the cathedral

http://www.agpa.uakron.edu/p16/lesson-print.php?id=nanofiber_chocolate_factory

-Nanometer is one billionth (1×10^{-9}) of a meter, which can be about 3 to 5 atoms in width.

http://search.yahoo.com/search;_ylt=A0oG7mOvyPJPOj0AFuVXNyoA?p=analogy+for+polymer+size&ei=utf-8&fr=aaplw&xargs=0&pstart=1&b=11&xa=Azc.TeenpHk8uUaR3lYmeQ--,1341397551

-Polymer dimensions

Activity 2 –

Polly's Morning Discovery

Polly is an imaginary teen. She wakes to the sound to her alarm clock (possibly made of polystyrene –a hard low-cost plastic which can be molded into a shape). The sheets and blankets on her bed are most likely made from a combination of a natural polymer (cotton) and polyester like Dacron. Polly gets out of bed her feet landing on a soft carpet. This polymer carpet can be made from a myriad of polymer fibers. This industry is continually looking for new ways to make carpet softer, easier to clean, and aesthetically pleasing to the buyer. Off to the bathroom to brush her teeth Polly finds her toothbrush, made of predominantly nylon, and toothpaste that contains polyethylene glycol, a low-toxicity and low-hazard risk polymer and maybe carboxymethyl cellulose, a polymer thickener, in the medicine cabinet. The cabinet is made of pressed wood fiber (cellulose polymer). As she reaches for the shower door she realizes that it is no longer made from glass but is a clear plastic (acrylic), and the shower bed is also a high-density polymer resin (H.D.P.). In the shower the shampoo and liquid soap (Polyquaternium-10, Polyquaternium-7, Polyquaternium-11, and/or Guar hydroxypropyltrimonium chloride. and silicones that may also be included dimethicone, amodimethicone, cyclopentasiloxane, cyclomethicone, dimethicone copolyols, or dimethiconol) bottles are marked with the HDPE recycling symbol. There is even a plastic squeegee with a note from Mom to wipe down the new shower and spray with a transparent polymer coating (TPC) surface protector. Drying off with a towel (rayon) Polly returns to her room (walking on tile floors made of polymers (PVC) and wood floors (Cellulose) coated with polymers (polyurethane) to put on her clothes, mostly cottons blended with polymer (polyester) for better stretch, resistance to soiling and durability.

Polly heads to the kitchen to make a lunch for school and used a plastic wrap (polyvinylidene chloride) to wrap her sandwich, plastic baggies (LDPE) for snacks and a plastic container (polystyrene) for her muffin. Books & papers are also made of cellulose Polly realizes as she packs them into her book bag. Pouring hot water over a teabag in her Styrofoam cup, she slips into her Crocs (Croclite), puts in her headphones and heads to the bus stop. From music she listens to the seat on the bus and in the classroom, Polly can trace the manufacturing of each product back to a natural or man-made polymer molecule. So, "what's all the fuss about?" she wonders as she walks into her first period class.

1. List 10 polymers that Polly encounters in her morning.

2. Research each polymer and answer 3 questions about each

a. What is the polymer made from? (Source material)
b. What process that makes this polymer?
c. What is the end product of this polymer? (What can it be made into?)

3. Answer Polly's question, "What is the fuss all about?"

Activity 3 –

Researching a Polymer Name ____________________

The polymer to be explored is ____.

This polymer is used to make ____.

Chemical formula for this polymer ____.

Physical structure of this polymer ____.

Raw material of this polymer____.

Chemical properties____.

Physical properties____.

Process used to make the polymer____

Uses ____.

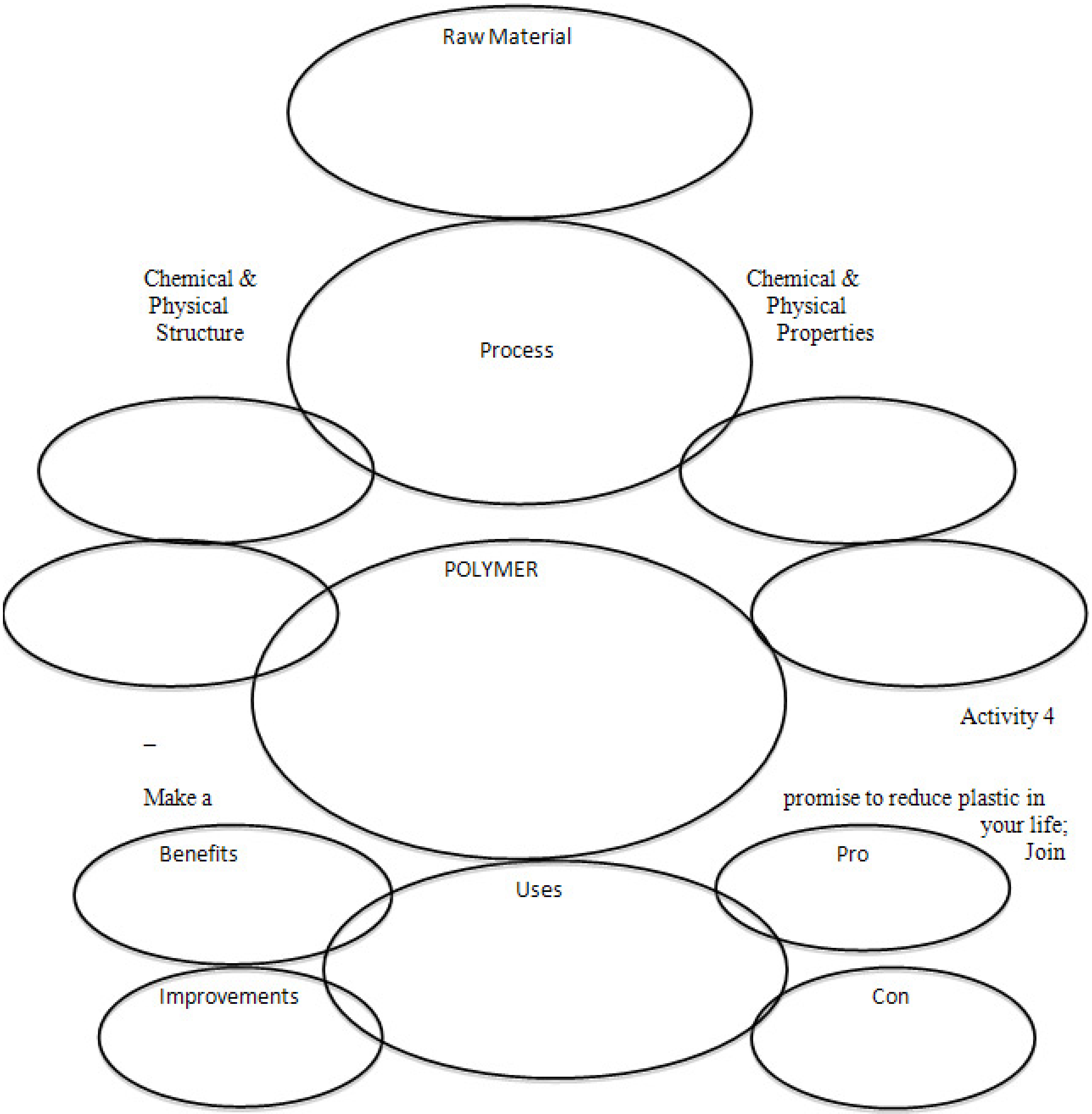
Benefits of the polymer ____.

Possible improvements____.

Pros of using this polymer____.

Cons of using the polymer____.

Graphic organizer for Polymer Research Name __________________



Activity 4 – Make a promise to reduce plastic in your life; Join

http://5gyres.org/the_5_gyres_plastic_promise

Activity 5 –

Tapped Worksheet Name______________________

1. The movie says that by __________________2/3 of the world will lack access to clean water.

2. Who controls bottle water? ____________________________

3. How much of Earth's surface is covered in water? _______%

4. How much of the Earth's water is drinkable? ___________%

5. Name the 3 largest water bottling corporations ____

6. In the next 20-25 years, no matter where you live, clean water access will be an issue due to changes in ________________.

7. ____________ pumped millions of gallons of water from the lake in Atlanta during a level 4 drought in 2007 even though severe restrictions on local residents & businesses were in effect.

8. How do bottled water companies imply tap water isn't healthy? What do they say in their advertisements?

____

____

9. How much of bottled water we purchase is just filtered tap water? _______ %

10. Who at the FDA is responsible for overseeing bottled water regulations? _______________

11. Who does the tests on bottled water? _______________

12. How often are Municipal (tap) water sources tested? ___________________

13. Of 80 million single serving plastic bottles used daily, how many end up in landfills? ___________

14. The average world recycling of beverage containers is ________%. The US is ____________%.

15. What is the return rate in Michigan with its 10¢ deposit ___________%?

16. ______________% of Americans don't have curbside recycling

17. In 2008, the Western Garbage patch jumped to _______ times more plastic than plankton?

Name 3 things listed in the credits that YOU can do.

18. ____

19. ____ 20.
____

Activity 6–

5 *Most Dangerous Myths of Recycling* found at
http://www.ilsr.org/the-five-most-dangerous-myths-about-recycling/ or at
http://www.grn.com/library/5myths.htm

The Five Most Dangerous Myths About Recycling

MYTH #1: We can recycle only 25 to 30% of our solid wastes.
MYTH #2: Recycling is more expensive than trash collection and disposal.
MYTH #3: Landfills and incinerators are more cost-effective and environmentally sound than

recycling options.
MYTH #4: Landfills are significant job generators for rural communities.
MYTH #5: The marketplace works best in solving solid waste management problems; no public-sector intervention is needed.

Activity 7–

E xamine one aspect of nanotechnology– history, idea, or product

X plain how this technology will affect the future of the planet

P review articles, books, websites, video – LOOK for CURRENT TECHNOLOGY

L ist ideas and sources into a letter– formulate 3 questions to ask

O rganize ideas & sources and connect to CURRENT practice– Write a letter

R ead research and respond what you learn

E ngage others in getting involved through presentation of materials

Appendix A

Implementing District Standards

CINQ5 Use appropriate tools and techniques to make observations and gather data.
CINQ6 Use mathematical operations to analyze and interpret data– metric system of units
D11 - Describe how atoms combine to form new substances by transferring electrons (ionic bonding) or sharing electrons (covalent bonding).
D12 - Explain the chemical composition of acids and bases, and explain the change of pH in neutralization reactions.
D13 - Explain how the structure of the carbon atom affects the type of bonds it forms in organic and inorganic molecules.
D14 - Describe combustion reactions of hydrocarbons and their resulting by-products.
D15 - Explain the general formation and structure of carbon-based polymers, including synthetic polymers, such as polyethylene, and biopolymers, such as carbohydrate.
D16 - Explain how simple chemical monomers can be combined to create linear, branched and/or cross-linked polymers.

D17 - Explain how the chemical structure of polymers affects their physical properties.
D18 - Explain the short- and long-term impacts of landfills and incineration of waste materials on the quality of the environment.
D19 - Explain how chemical and physical processes cause carbon to cycle through the major earth reservoirs.

NSE Standards Covered

LS 1a - Cells have particular structures that underlie their functions.
LS 1d - Cell functions are regulated.
UCP 1 - Systems, order, and organization
UCP 3 - Change, constancy, and measurement
UCP 5 - Form and function
SAI 1 - Abilities necessary to do scientific inquiry
SAI 2 - Understandings about scientific inquiry
ST 1 - Abilities of technological design
ST 2 - Understandings about science and technology
HNS 1 - Science as a human endeavor
HNS 2 - Nature of scientific knowledge
HNS 3 - Historical perspectives

Appendix B

Materials needed:

Polymers and their Characteristics

Polymer	Polyethylene LDPE or HDPE	Polypropylene PP	Polyvinylchloride PVC	Polytetra-fluoroethylene PTFE, Teflon	nylon/polyester /acrylic/vinyl	Polystyrene
Monomer	ethylene	propylene	vinyl chloride	tetrafluoro-ethylene	diamine + dicarboxylic acid	styrene
Basic formula	$CH_2{=}CH_2$	$CH_2{=}CHCH_3$	$CH_2{=}CHCl$	$CF_2{=}CF_2$	$HOOCCH_2CH_2CH_2COOH$+ $H_2N\ CH_2CH_2CH_2$ $CH_2CH_2CH_2NH_2$	$CH_2{=}CHC_6H_5$
Raw Material	petroleum	petroleum/ natural gas	petrochemicals	petro-chemicals	hydocarbon from coal	petroleum
Properties	soft & waxy or solid& translucent	soft & elastic or hard solid	strong rigid solid	resistant smooth solid	fermentation alcohol/crude /natural.gas	hard rigid clear solid, flammable
Examples	Plastic wrap/bags or bottles/toys	carpet upholstery	pipes siding, flooring. tents, sheeting	non-stick surfaces electric insulation	fibers for clothing and household items	synthetic rubber, toys cabinets foam packaging
Polymer	**Bakelite**	**Cellulose Acetate/Rayon**	**Wool**	**Silicone**	**Rubber**	**Starch**
Basic formula	$-OC-C_6H_4-COO-CH_2-CH_2-O-$	$C_6H_{10}O_5$	$NH_3-CHR-CO-NH-CHR-CO_2$	SiO_2	C_5H_8	$(C_6H_{10}O_5)_n$
Properties	doesn't burn	holds onto water/ emulsifier/ anti-caking agent....	hard wearing, absorbs moisture, doesn't burn over a flame, lightweight, versatile, does not wrinkle easily, resistant to dirt and wear and tear.	Low thermal conductivity, chemical reactivity & toxicity, thermal stability, repels water, forms watertight seals. won't support microbiological growth.	resistance to water & low temperatures, resilient, hard to tear and resists abrasions, withstands impacts due to its strength and has slow buildup of heat.	hard, adhesive, cohesive, springiness, gumminess, chewiness
Examples	dishware telephone headsets	Screwdriver handles/ films /fibers	sweaters, dresses, coats, suits, jackets, pants, lining of boots, blankets and carpets.	semi-conductor, silicates, silly putty, pottery, enamel, abrasives, glass	tires, hoses, belts, lining, gloves, recreational balls, erasers, footwear,	food additive, clothing stiffener, adhesives, packing peanuts, ceiling tiles...

Poster showing the size of nanoparticles (found at *http://www.sciencelearn.org.nz/Contexts/Nanoscience/Sci-Media/Images/Nanoparticle-size-comparison)*

Plastics and Polymers *http://www.nobelprize.org/educational/chemistry/plastics/readmore.html*

Videos: *Tapped* - Stephanie Seochtig

Assembly Line: *Baltimore Toolworks* Chisels - http://videos.howstuffworks.com/science/polymer-videos-playlist.htm#video-27863

Appendix C

Resources for Students

AgResearch. Fabrics get high tech treatment. *http://www.biotechlearn.org.nz/news_and_events/news/2007_archive/fabrics_get_high_tech_treatment.* 2007- nanoparticles and fabric

American Chemistry Council. *History of Polymers and Plastics for Students. http://plastics.americanchemistry.com/Education-Resources/Hands-on* .2012 - history, examples and information on polymers & plastics

EPA site: Green & growing CT *http://www.ct.gov/dep/cwp/view.asp?a=2703&Q=423114&depNav_GID=1634* - 2012-

CT government site, green practices in the state. *Plastics/Introduction-to-Plastics-Science-Teaching-Resources/History-of-Polymer-and-Plastics-for-Students.html*

Introductory Chemistry; the atom. *http://www.chem4kids.com/files/atom_intro.html* - 2012 great periodic table an chemistry website

Nanotechnology videos *http://www.nanofolio.org/images/gallery05.php http://dep.state.ct.us/wst/remediation/brownfields/brownfields.htm. http://www.ec.gc.ca/acidrain/*

Solar paint *http://pubs.acs.org/doi/abs/10.1021/nn204381g?journalCode=ancac3*

Strange Matter *http://www.strangematterexhibit.com/whatis.htm* l - basic description of materials science

Watt, John. The Royal Society. What happens when gold and wool combine? *http://www.sciencelearn.org.nz/Science-Stories/Ever-Wondered-Series-1/Sci-Media/Video/Ever-Wondered-Series-1-Episode-6/Ever-Wondered-episode-6-part-1*

Appendix D

Resources for Teachers

American Chemistry Council: Teaching Plastics *http://www.americanchemistry.com/s_plastics/doc.asp?CID=1123&DID=4982*

American Chemistry Council: *Tensile strength and other testing of plastics http://www.americanchemistry.com/s_plastics/hands_on_plastics/activities/industrial_testing_lesson/industrial_testing_lesson.html-* plastics & their strength for polymer lab

Berger, Michael. *The promise of nitric oxide-releasing nanoparticles as wound healing agents. http://www.nanowerk.com/spotlight/spotid=24750.php* .2012 - promise of the use of Nano particles in medicine

Berger, Michael. *Polymer carpets - a new class of nanomaterials for NEMS and MEMS. http://www.nanowerk.com/spotlight/spotid=17875.php.* 2010 - new polymer carpets are multilayered and made of many polymers

Carroll, David L. and Gunsch, Claudia K. *Nanoparticles and the Environment. http://photonics.com/Article.aspx?AID=44805* . 2010-article explains reasons for caution in the introduction of nanoparticles to the environment

Cassaro, Ryan. *Block Copolymers.* Retrieved 5/ 24/ 12 *http://www.blockcopolymers.com/-* defines block copolymers

Copeland, Tracy. *Dow Researchers Win Award for Polymer Invention. https://www.dow.com/facilities/namerica/texops/news/20070713a.htm.* 2007 - new polymers. Eggling, Sue. *Molecules* . Retrieved 5/24/12 *http://dl.clackamas.edu/ch104-03/molecule.htm* - facts about molecules, compounds & bonding

Eriksen, Marcus. *What is the problem? Plastics made to last forever designed to throw away.http://5gyres.org/what_is_the_problem/plastic_accumulation* - website and blog showing the impact of plastic on the ocean

Goldstein, Miriam C., Rosenberg, Marci. Cheng, Lanna. *Increased oceanic microplastic debris enhances oviposition in an endemic pelagic insect. http://www.cawrecycles.org/files/Scripps_PlasticIncreaseStudy_May2012_0.pdf* . 2012 - Scripps microplastic study, insects lay eggs on small pieces of plastic uneaten by predators

Hudson, RL. *Thermoset vs. Thermoplastic Materials.* Retrieved 5/ 24/ 12 *http://www.rlhudson.com/publications/techfiles/thermo.htm.* -Describes the differences between thermosets and thermoplastics

IUPAC. Hydrocarbons- Goldbook. *http://goldbook.iupac.org/H02889.html* - all the know levels of hydrocarbons, and effective picture of the vast number, variety and impact

Moore, Charles. "*Out in the Pacific Plastic Is Getting Drastic.*" UN Environment Program. *http://marine-litter.gpa.unep.org/documents/World's_largest_landfill.pdf*

Nano Technology Now *http://www.nanotech-now.com/current-uses.htm.* 2008

Nobelprize.org. Plastics and Polymers *http://www.nobelprize.org/educational/chemistry/plastics/readmore.html.* 2007

Noller, Carl R. Usselman, Melvyn C. *Organic Compounds, Carbon bonding.* Encyclopedia Britannica. Retrieved 5/19/12 *http://www.school.eb.com/eb/article-278309?query=carbon%20bonding&ct=car*

NYU: Carbon *http://www.nyu.edu/pages/mathmol/modules/carbon/carbon1.html*

NYU: Hydrocarbons Page *http://www.nyu.edu/pages/mathmol/library/hydrocarbons/*

Peacock, Andrew. Calhoun, Allison. *Polymer Chemistry Properties and Application http://books.google.com/books?id=FPrfQJuDE3YC&pg=PA160&lpg=PA160&dq=polymers+in+toothpaste?&source=bl&ots=6C73Th2Y9B&sig=RKPDIv5UcpqhKWUOTZfpl3aVIto&hl=en#v=onepage&q=polymers%20in%20toothpaste%3F&f=false* - describes polymers in everyday things

United States Environmental Protection Agency. *Polymer Exemption Guidance Manual. http://www.epa.gov/oppt/newchems/pubs/polyguid.pdf.* 1997 - EPA regulations for polymers

Weirssermel, Klaus. *Raw Material- Polymer Interrelations-Today's Choice-Tomorrow's Options. http://pac.iupac.org/publications/pac/pdf/1980/pdf/5202x0265.pdf* .1980- raw materials of polymers