Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
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Problem Based Chemistry: How do I Make a Lake Paint?

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Introduction

I teach at Cooperative Arts and Humanities Magnet High School in New Haven, CT. It was originally started as a cooperative school between Hamden and New Haven Public School. Today the school currently accepts 65% New Haven residents, and 35% suburban residents from 30 outlying suburban districts. All students have to enter in the magnet lottery and are chosen by random, but preference is given to incoming students with siblings currently enrolled in the school. There are about 700 students in the student body, demographically in 2013-2014, 50% African American, 25% Hispanic, 22% Caucasian, 3% Asian, 67% female, 33% male, 2% limited English proficiency, 58% eligible for free or reduced-price lunch.

The students choose an art to focus their studies on for 90 minutes a day for four years: theater, dance, music (choir, band, or orchestra), visual art and creative writing. There are opportunities to try out art outside your major in elective classes and in the extensive after school program. The students also are required to take the standard compliment of core academic classes: English, mathematics, history, science, and foreign language, as well as a technology and a physical education class. The school offers a handful of electives, and pushes students to achieve highly, and to take AP classes during their junior and senior year, with a major goal of graduating all students, and all students getting into and going to college.

This unit is designed for juniors enrolled in regular level chemistry class, likely diverse in background, skill, and social-emotional skill, and maturity. Students below grade level in both reading and math skills will still get a lot out of this unit, and in many ways it is designed to reach them, as they are often disengaged from many chemistry topics. This unit expects the students to be able to do basic math functions, and be able to read material at about a 7 th grade reading level, but can be modified for students of different ability.

Content Objectives

- The world can be divided into three types of molecules: ionic, polar and non-polar. [12]
- All molecules are attracted to each other by London dispersion forces. [10]
- Polar molecules line up like magnets and are attracted to each other by dipole-dipole interactions.
- Ionic compounds are a network of oppositely charged particles that are extremely attracted to each other.
- Some molecules can share a hydrogen that is loosely bonded to both of them in hydrogen bonding.
- Solvent molecules that are alike can be miscible with each other.
- Polar and non-polar molecules are not miscible, and don't dissolve each other.
- Molecules called surfactants exist that have polar and non-polar sections, and those sections can bond to other alike molecules.
- Dissolving ionic and polar molecules in water can decrease the strength of the dipole-dipole or ionic interaction between those molecules because the polar water molecules get in the way. [10,12]
- Surfactants can be made by adding plant oil to strong base, and separating the fatty acids from the triglycerides. [8,12]
- Lake paints can be made with plant oil, pigment and binder. Binder allows the pigment to be spread out evenly, the oil base allows the paint to dry slowly, and the pigment gives the paint its color. [8,16]

Background

The World Can be Divided Into Three Types of Molecules: Ionic, Polar and Non-Polar

All the molecules in the world are divided into two categories: ionic compounds, polar molecules and non-polar molecules. Ionic compounds are a vast 3D grid of charged particles that are attracted to all oppositely charged particles that surround them, creating a network of highly connected particles. Polar molecules have a positive and a negative side, and are like the Earth with a north and a south pole. Each atom in a polar molecule has a tendency to want to be either positively charged or negatively charged molecules. Non-polar molecules are like most other objects, they are made up of uncharged atoms, they do not have a negative and positive side, and are overall neutral.

Molecules are Attracted to Each Other

Molecules interact with each other in non-covalent ways, these are divided into three types of intermolecular forces: ionic bonding, hydrogen-bonding, and Van der Waals forces which includes subsets of: London dispersion forces (which also goes by induced dipole-induced dipole forces), dipole-dipole forces, and dipole-induced dipole forces. These attractions are electrostatic in nature, and stem from interactions in the electron clouds of valence electrons of the molecules in question.

All molecules are attracted to each other by Van der Waals forces. Different types of molecules interact in different ways. The strength of the interactions depends on the charges on the atoms within the molecules and the bonds inside each molecule. The greater the polarity or charge on the individual molecules, the more energy is given off by attaching them to each other, and the stronger the intermolecular interaction.[12] Each type of intermolecular attraction has an optimum distance where the attraction is maximized and repulsion is minimized, this is the most energy efficient state for these two molecules.[10] The optimum distance is called bond length, and generally the stronger the attraction, the lower the energy state, and the shorter the bond length. Distances that are shorter than optimum create a repulsive force between the molecules. Distances that are greater than the optimum still have attractive forces, but forces are decreased due to an inverse squared relationship with the distance between the molecules (see the explanation of Coulomb's Law later in this unit.)[10]

Ionic Bonding

Ionic bonding occurs when a positively charged molecule is nearby a negatively charged molecule. These oppositely charged molecules, or ions, have an electrostatic attraction to each other. Positively charged molecules are those that have fewer electrons than protons. Negatively charged molecules are the opposite, and have more electrons than protons.

For example, an ammonium molecule (NH_4^+) has one fewer electron than protons. Nitrogen contributes 7 protons and 7 electrons (5 of the electrons are valence electrons), and each of the four hydrogens contributes 1 proton, and 1 valence electron. There should then be 9 valence electrons in this molecule, but it only has space for 8 valence electrons, according to the Octet Rule and the electron requirements of each atom. One of the valence electrons is not used, and is essentially lost. This leaves the molecule with a total of 10 electrons (including valence and kernel), even though it has 11 protons. Protons are positive, and the overall balance of charge is +1.

A hydroxide ion (OH^-) has one more electron than it has protons. Oxygen contributes 8 protons and 8 electrons (6 of the electrons are valence electrons), and the hydrogen contributes 1 proton, and 1 valence electron. There should then be 7 valence electrons in this molecule, but it has space for 8 valence electrons, and according to the Octet Rule and the electron requirements of each atom, it needs one more valence electron. It will take an electron from a nearby atom or ion that is able to donate one. This leaves the molecule with a total of 10 electrons (including valence and kernel), even though it has only 9 protons. Electrons are negative, and the overall balance of charge is -1.

The charges on molecules often have a particular location in the molecule where they settle, this is due to atoms pulling on their electrons with greater strength, a property known as electronegativity. Positive charges settle on the atoms with the lowest electronegativity, while negative charges settle on the atoms with the highest electronegativity. The relative electronegativities of the atoms in our example molecules are H < N < O. The (+1) for the ammonium ion will be located on one of the hydrogens, and the (-1) for the hydroxide ion will be located on the oxygen. This creates the positive and negative ends of the molecule, essentially a (+) and (-) pole, which is a property also known as polarity, or having a dipole moment. According to the equation for Coulomb's law, F=k((q1q2))/r^2 the force of attraction between the charged objects (the NH_4^+ and OH^- ions in our case) is proportional to the charge on the objects multiplied by each other (q1 & q2) divided by the distance between the objects (r) squared. Basically, the larger the charges on the ions, the larger the force of attraction between them, and the closer the molecules are to each other, the larger the force of attraction between them.

Polar Molecules

Polar molecules are built by connecting atoms with differing electronegativities. When atoms with high electronegativity are bonded to atoms with low electronegativity, the electrons are shared unevenly. Electrons gather more closely to the atom with high electronegativity. This causes a partial negative charge at one end of the bond, and a partial positive charge at the opposite end of the bond. This results in a similar polarity to ionic bonds, but not as strong. It is also referred to as polarity, and dipole moment. Polar molecules can have multiple polar bonds. Often the polar bonds line up asymmetrically, sometimes causing one partial positive side and one partial negative side, but other times causing more than one area of partial positive and partial negative charge.

Non-Polar Molecules

Non-polar molecules exist in two different categories. The first type consists of connecting atoms with very similar or the same electronegativity. Bonds between atoms with similar pull on electrons means the electrons are shared relatively evenly, and have insignificant charge separation, or perfectly evenly, and creates a neutral bond.

The second type consists of connecting atoms with differing electronegativities in extremely symmetrical shapes. Polar bonds exist between pairs of atoms because they have significantly differing electronegativities, but since the dipole moments line up in opposite directions, the dipoles (which are basically electromagnetic forces) cancel each other out. They are like evenly matched teams in tug-o-war, stalemate occurs. The dipoles cannot be felt by neighboring molecules. So, even though there are polar bonds within the molecule, the overall molecule is non-polar.

London Dispersion Forces/Induced Dipole-Induced Dipole Forces

London dispersion forces are forces of attraction between two molecules. When one molecule gets close to another molecule, the electrons in each molecule repel each other, inducing temporary polarity in both molecules. The temporarily positive end of one molecule is attracted to the nearby temporarily negative charge on the neighboring molecule. This induced dipole–induced dipole interaction is the weakest of the types of intermolecular interactions, and is the only type of interaction that occurs between two non-polar molecules. Non-polar molecules are therefore not strongly attracted to each other when compared to other types of molecules, and their corresponding interactions.

Van de Waals interactions are always present, but other types of interactions can compete with and overshadow them. [10]

Dipole-Dipole Forces

Dipole-dipole forces are forces of attraction between two polar molecules. When one polar molecule gets close to another polar molecule, the molecules orient themselves so the partial positive of one molecule is close to the partial negative of the neighboring molecule. They are then attracted to each other. This dipole–dipole interaction is the strongest of the types of Van der Waals interactions, but is not as strong as ionic bonding. Polar molecules are therefore significantly attracted to each other when compared to other types of molecular interactions.

Dipole-Induced Dipole Forces

Dipole-induced dipole forces are forces of attraction between one polar and one non-polar molecule. When the polar molecule gets close to the non-polar molecule, a temporary polarity is induced in the non-polar molecule, much like with London dispersion forces. The permanently charged end of one molecule is attracted to the nearby temporarily charged end on the neighboring molecule. This dipole–induced dipole interaction is the second weakest of the types of intermolecular interactions. Non-polar molecules are therefore not strongly attracted to polar molecules and other types of interactions can compete with them, and overshadow them. [10]

Hydrogen Bonding

Hydrogen bonding occurs when a polar molecule has a very electronegative atom (N, O, F, S) with a non-bonding lone pair of electrons, and a neighboring molecule has a very electronegative atom bonded to a hydrogen atom. [1] The hydrogen can loosen its covalent bond with its atom, and interact with both its own electronegative atom, and the unbonded electrons on the neighboring electronegative atom. Hydrogen bonds usually are asymmetrical, with the hydrogen having a shorter and stronger connection to the atom in its own molecule, but occasionally can be perfectly symmetrical. [1] Hydrogen bonds are known to stabilize many types of molecules. [1] Polymers can be stabilized by impermanent cross-links made of hydrogen bonds. The complimentary bases in DNA are connected via hydrogen bonding, which provides a stable interaction to allow DNA to “zip-up”. [10] This bond is significantly weaker than the covalent bond between bases in the DNA sequence, allowing DNA to more easily “un-zip” than be completely broken. [10] Hydrogen bonds in smaller molecules make liquids and crystalline solids more stable, viscous and cohesive than similar small molecules that do not hydrogen bond. [1] The classic example of this is water. Comparing the properties of molecules of C, N, O, and F bonds with H, only water has the highest melting and boiling point, and extremely strong cohesive properties. [1] CH_4 is incapable of hydrogen bonding, because carbon is not electronegative enough, NH_3 has only one lone pair available for hydrogen bonding, and HF has only one hydrogen available for bonding, but water has two hydrogens available, and two lone pairs available for hydrogen bonding, doubling the hydrogen bonding capacity, making it very stable and cohesive. [1]

Miscibility

Polar molecules can mix with and dissolve other polar molecules and ionic molecules. Non-polar molecules can mix with and dissolve other non-polar molecules. Polar molecules and non-polar molecules do not mix, and behave as if they even repel each other.

Molecules That Have Polar and Non-Polar Ends

Some very large molecules have different sections, sometimes with a polar section and a non-polar section. There are several very common groups of linked atoms that are attached to molecules of atoms that are called functional groups, or for short ‘R’ groups. Some R-groups are polar, like alcohols, aldehydes, and carboxylic acids while others are non-polar like methyl groups, (CH_3). [10] It is possible to covalently bond a polar functional group on one side and a non-polar functional group on another side of a molecule. Having one end of a molecule that is polar, and one end non-polar means you can get one end to stick to other polar molecules (called hydrophilic), and the other to stick to non-polar molecules (called hydrophobic). [10] These molecules are called surfactants, and they have many uses. (Students should think about and brainstorm ideas about what a molecule like this might be able to do.) [12]

Hydrophobic Effect

The hydrophobic effect is a result of many energy factors present when non-polar molecules attempt to mix with water. Non-polar molecules are only weakly attracted to polar water, but water is strongly attracted to itself because it is an excellent hydrogen-bonder. It is more favorable for the water to stick to itself by dipole-dipole and hydrogen-bonding interactions than to the non-polar molecules by only dipole-induced dipole bonding. [12] These conditions create a situation where it is favorable for non-polar molecules to aggregate in pockets away from the water. [10] Both the non-polar molecules and the water can bond to themselves, but not to each other. It is also worth noting that the water molecules will bond with each other around the surface of the surfactant pocket. [4] To break these bonds takes energy, this creates a sort of barrier. [4] Once they are in this configuration, gaining the energy to break free can be difficult. If the non-polar substance has a different density than that of water, and there is enough quantity the solvents will repel each other enough to form layers, one on top of the other.

In the case of large molecules like proteins, the hydrophobic effect causes molecules to fold and to orient themselves so the polar or charged ends are on the outside of the pocket, and their non-polar ends are folded inside. [11] The non-polar groups then weakly bond with themselves by London dispersion forces, the polar groups bond to the water molecules by whatever means they are able, dipole-dipole, hydrogen-bonding, ionic bonding. [11] The water will still construct a hydrogen-bond energy barrier on the outside of the pocket, but it is compounded frustrated landscape proteins move in. [4] They are composed of long chains, sometimes with branches, and have very limited mobility, and can often get stuck in particular configurations because they are difficult to move. Once in a favorable configuration it is very stable. [11]

Surfactants Attenuation With Water: Do Surfactants Prefer to Dissolve in Water or Oil?

Since the scope of this unit encompasses intermolecular forces in biological systems, attenuation with water needs to be considered. When comparing the interactions of polar or ionic portions of surfactants in aqueous systems, and in non-aqueous, ionic bonding in aqueous systems are significantly weaker.

When dissolved in water, the hydrophilic ends of the surfactant can interact with water by dipole-dipole, hydrogen bonding (if it can accept or donate hydrogen), or ionic bonding with OH^- and H^+ ions in neutral water. Bonding to the water is favorable, it increases the options for what the polar portions can bond to, and the choice between bonding to the water or to itself is muddled. Water therefore obstructs the dipole-dipole and ionic interactions, and diminishes their strength. [12] Meanwhile, the hydrophobic (non-polar) sections will fold inward due to the hydrophobic effect and bond to itself via induced dipole-induced dipole forces.

When dissolved in oil, the hydrophilic ends of the surfactant will fold inward, and while isolated from water, hydroxide and hydronium ions, will bond to each other by either dipole-dipole or ionic bonding. [11] This happens as if in a vacuum, and the attraction between the positive and negative poles becomes very strong due to the very small distance between them (refer to the explanation of Coulomb's Law.) [10,12] Simultaneously, induced dipole-induced dipole bonds occur between the non-polar ends of the molecule and the non-polar solvent molecules. [11]

When comparing all the factors and types of bonding in both situations, dissolving in oil is more favorable than dissolving in water. [12] Ionic bonding and dipole-dipole bonding are stronger than induced dipole-induced dipole bonding, so choosing the situation that maximizes the stronger type bonds is more favorable. Surfactants can and will dissolve in water, but if given the option, due to stronger intermolecular interactions it prefers to be dissolved in a non-polar solvent.

Surfactants: Plant Oil + Base = Soap

Surfactants can be produced by reacting fatty acids with lye (sodium hydroxide). [12] Adding sodium hydroxide solution to oils causes detachment of the fatty acids. The oxidized fatty acid becomes an anion, and can bond to the sodium cation, allowing a network of large clumpy non-polar molecules to bond ionically at one end. This means it can form a tangled network. As the soap cools, it becomes a solid. [12] The fatty acids have a hydrophobic and a hydrophilic end, allowing them to stick to both polar and non-polar molecules.

Soaps are made from plant oils, which are triglycerides. Triglycerides are 3 long chains of carbons, either saturated or unsaturated with hydrogen atoms, and connected to each other by a glycerol. [10] They are esters, but the carbon chains are so much larger than the ester they are essentially non-polar molecules. [1] These molecules can by hydrolyzed with a base. Sodium hydroxide is often used, and produces 3 non-polar chains with an ionized oxygen at one end (fatty acid), all ionically bonded to a sodium ion, and a glycerin molecule.

Paint: Plant Oil+ Pigment + Binder = Paint

Paints are similar in starting materials to surfactants, triglycerides. Because triglycerides are very large molecules they have a lot of London dispersion forces, they are fairly well bonded to each other for non-polar molecules, and are a fairly thick liquid at room temperature. [12] Most plant oils are unsaturated (have some C=C double bonds). As they out in the presence of oxygen, the carbon atoms that are double-bonded to each other start to bond to other unsaturated carbons in double bonds in nearby chains. Each unsaturated carbon that bonds leaves a carbon at the other end of its previous double-bond destabilized. [12] The destabilized carbon then forms a cross-link bond to another unsaturated carbon in another nearby triglyceride molecule. [12] This chain reaction keeps going until essentially all the unsaturated carbons have bonded to other unsaturated carbons. This essentially turns the thick liquid into one huge flat molecule with many connections. It is now a web of connected chains, which is an ideal solid to trap pigment molecules in place. [16] Plant oils take a fairly long time to complete this drying process they are highly desired for paints. [2]

Lake Pigments

Lake pigments were developed in renaissance times, and are essentially oil paints that hold a water soluble pigment. [6] Oil paints are desirable for artists because they dry slowly, staying wet for long periods of time. [12] This property allows the painter to keep working on a section, blending, changing shade or hue over several days or weeks, allowing for a lot of flexibility. Artists do want the oils to dry eventually, so they are permanent, but not too fast, so, not all oils are created equal, linseed is a favorite. [2,8]

The problem is that oil based pigments don’t often occur in nature in robust colors, the robust colors are often salts that are soluble in water, and not in oil. [2] Water soluble salts are polar and will not mix with non-polar oils. They will form large pockets or layers above or below the drying oil. This is not ideal for painting. It could cause uneven color, bubbling, cracking, or prevent the oil from drying altogether. Some polar pigment particles can be coaxed into diffusing in oil even though they would rather not dissolve. This can be done primarily with aluminum salts. [8,9] Aluminum potassium sulfate (commonly known as alum) will bond to polar pigments, and creates small globular particles. [2,9] These particles will diffuse evenly in the oil, and get stuck in the web of crosslinking fatty acids as the oils dries. These type of pigments are called Lake pigments.

Classroom Activities

Lesson 1: Polarity Sort: What Kinds of Molecules are There?

Students will work in small groups to use highlighters to identify atoms as high, middle, or low electronegativity using a chart of atoms electronegativities. Students will then sort the molecules into two piles: polar molecules and non-polar molecules. Students will then share their methods and reasoning with the class, and compare to accepted values.

Lesson 2: Molecule Build: How do I Figure out a Molecule's Correct Type?

Students will build models of common molecules (like NH_3, CH_4, H_2O, HF) in molecular model sets and also with balloons. They will then label the balloon models with the partial positive charges by coloring with a red marker. Label the partial negative charges by coloring with blue marker. Students will then share their models and reasoning with the class.

Lesson 3: Molecular Speed Dating: How do Molecules of Different Types Interact With Each Other?

Each student will take one molecular model that they helped build in their group from Lesson 2. Students will break out into individuals, and "speed date" another molecule for 5 minutes. During that time the dating pair will evaluate the type of molecule they are dating: non-polar covalent, polar covalent, ionic, charged ion; and determine the types of interactions at work between them: London dispersion forces, dipole-dipole, dipole-induced dipole, ionic attraction, ionic repulsion, and hydrophobic effect, and rank the "date" as "terrible", "okay", "good", "great". After 6 "speed dates", students will rank each date from best to worst. They will then look at the list of all potential dates and pick the ideal date and the least ideal date. Students will justify their reasoning for each rank and choice. Students will share their methods.

Lower level groups will be provided a chart with the type of molecule each molecule is, and a chart with diagrams and point values for each type of interaction. They will only have to match the molecule to its type from the chart, match it to the type of interaction, add up the points, and rank the molecular date (London dispersion forces = +1, dipole-dipole = +3, dipole-induced dipole = +2, ionic attraction = +5, ionic repulsion = -5, and hydrophobic effect = -5). They will also justify, but will share their reflections instead of methods.

Lesson 4: Molecular Attraction: What is Molecule Attraction/Repulsion Similar to in Real Life?

The teacher will explain and show real life analogies of the behavior of molecules will be given and explained in a lecture format. The students will listen, write notes, discuss, ask questions, and pose their own analogies for the types of intermolecular interactions.

Van der Waals Forces Analogies:

- when cars line up on the highway for no reason.
- when people line up for no reason.

- when people in survival situation movies, they group together. “Safety in Numbers”.

Molecules are attracted to each other in different ways, some stronger attractions than others, but they almost always prefer to be near other molecules than on their own.

Induced Dipole-Induced Dipole Interactions Analogies:

“Books in a Bookcase”: Books always end up together: stacked on a table, shoved in a locker/backpack, stored on a shelf. When they are on a shelf they are all lined up the same way: beginning-end: beginning -end: beginning -end, induced dipole molecules line up the same way (+ -) (+ -) (+ -).

“Parallel Parking”: Cars on the street are always parked parallel from front to back to front to back, or in a parking lot from driver side-passenger side.

Dipole-Dipole Interactions Analogy:

“Besties”. When 2 people who are exactly alike are friends, and they stick together all the time, just like two molecules that are polar covalent.

Dipole-Induced Dipole Interactions Analogies:

“Good-cop/bad-cop.”: The dipole is like the bad-cop, and won’t budge, the other has to be the good-cop, he has to flex a little, and will “help you out”, just like the molecule will temporarily be polarized.

“Frenemies”: When you start acting crazy, but only around your one crazy friend. You are temporarily crazy, just like a molecule is temporarily polarized.

Ionic Bonding Analogy:

“Opposites attract, siblings repel”: Romantic relationships are strongest when personalities complement each other, and siblings are the most romantically repulsive people we know. Ionic bonds can only occur when positives ions and negative ions are nearby each other, positive ions and negative ions repel other alike ions. This is one of the only times molecules would rather be alone than with other molecules. Think about it, would you rather go to prom alone, or with your brother/sister?

Hydrophobic Effect Demonstration:

“Oil & Water”: Everyone knows this example, so this is a demonstration rather than a real life analogy. Show how oils bead up in water in an attempt to get as far away as possible, and show how water does the same thing in a cup of oil. Use a visual aid, drop water in a beaker of oil, and drop oil in a beaker of water.

Lesson 5: Ionic Matchup Game: How do Ions Bond With Each Other?

Students will use refrigerator magnets to make ionic bonding pairs. Note to teachers: Small firm cylindrical magnets are ideal, the flimsy plastic magnets have no discernable poles, and neodymium magnets are too strong. The magnets need to be labeled, half with the (+) on the N side, half with (-) on the S side. This is so the (+) ions will only stick to (-) ions, and will repel other (+) ions, and vice versa. The magnets can be labeled with specific ions, like Na^+, K^+, F^-, Cl^-, etc... , or not. Students will choose a (+) or a (-) ion, and identify which ion it represents. They will then try to make ionic bonding pairs with other students’ ions. Students will write down all pairs that bond to each other.

For each bonding pair, students will write down the charges of each ion, and figure out how many of each positive and negative ion they would need to balance the compound to zero. Students will then write the ionic formula and name for each ionic compound. All compounds will be shared on the board with the class.

Lesson 6: Hydrogen Bonding Game: How Does Hydrogen Bonding Work?

Students will make hydrogen bonds by creating handshakes where there is one and only glove between them, and where each handshake has a left hand shakes a right hand. (gloved left hand + non-gloved right hand = 1 hydrogen bond.)

To illustrate how hydrogens can transfer from one molecule to another, the hands need touch middle fingers like in Figure 1 below. Carefully take the glove off the gloved hand, turn it inside out, put it on the ungloved hand, so that the glove is now inside out and on the other hand.

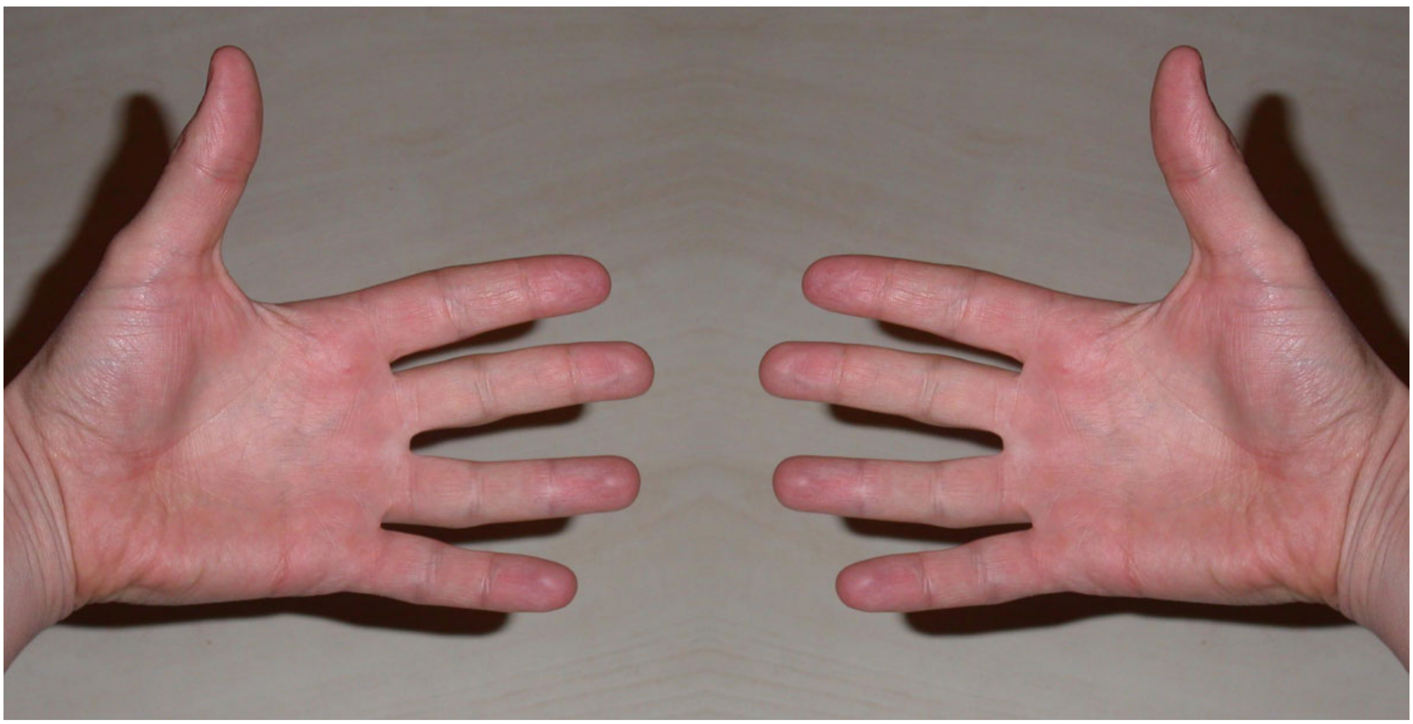

Figure 1: A photo of a left hand, mirrored for demonstration purposes.
Retrieved:https://commons.wikimedia.org/wiki/File:Paume_de_main.jpeg#/media/File:Paume_de_main.jpeg

Lesson 7: Miscibility Lab: What's Miscible With What?

Students will be given samples of oil, alcohol, water, salt, sugar, and petrolatum, along with the name, chemical formula, and type of molecule (polar, non-polar, ionic). Students have to mix each solid with each solvent, and each solvent with each other. Students will observe and record whether each pairing is able to mix. Students will then write rules for miscibility, and predict the outcomes of pairs of compounds based on their name, and formula.

Lesson 8: Soap Lab: How do I Make Soap?

Students will blend melted coconut oil with a solution of sodium hydroxide (lye) to make small bars of coconut oil based soap. Students will write the chemical equation with diagrams for saponification to release fatty acids from the coconut oil: lauric acid, and any of the other fatty acids. Saponification of the triglycerides in coconut oil will be done together as a model. Lauric acid is the most prevalent in coconut oil. [3]

Lauric acid + sodium hydroxide -> sodium laurate + water.

It is vital to make sure students understand and can explain why a water is produced and not a glycerol. This is because the fatty acids in coconut oil are carboxylic acids, and do not have a functional group on the other side of the carbonyl carbon. [3] The Hydrogen that exists there bonds to the OH^- to produce water. It is also useful to discuss oleic acid's saponification because it is a component of linseed oil which will be used in Lesson 10.

Lesson 9: Pre-lab Inquiry: What Ingredients of Lake Paints Can Mix With Each Other?

Students will use what they learned in Lesson 7 to develop a plan to test how the components of Lake paints interact with each other. In small groups they will develop a plan to test the miscibility of linseed oil, water, pigments, and aluminum potassium sulfate. Once the plan is developed and students are clear on what they want to test, how they will test it, and proper safety precautions, they will run their tests, analyze their results, and explain how the components of a lake paint are able to mix together.

Lesson 10: Paint Making Lab: How do I Dissolve the Pigment to Make a Lake Paint?

Students will plan a method of making lake paint using their knowledge of the ingredients, and what they learned from Lessons 7, 8, and 9. They have the same ingredients as Lesson 9, as well as solubility data, and suggested starting amounts based on an existing recipe for Madder Lake paint. [2] Ingredients: linseed oil, water, pigment, potassium aluminum sulfate to make lake pigment paint. [2] When ready with a method, and safety precautions, students will make lake paint, and try it out. Students can then share their lake paints with each other to create color palettes, and create small paintings. Students will evaluate which paints work the best, compare methods, share data and observations, and will write conclusions and reflections on the project.

Teaching Strategies

This unit uses a wide variety of teaching strategies for two main reasons: science (and especially chemistry) is hands-on, and I think students learn better when they are doing active work themselves. Some strategies employed in this unit are: engaging students with an essential question for each lesson, hands-on inquiry activities that require students to manipulate tactile items with their hands, discuss science concepts with their peers, cooperate with their peers towards a specific goal, evaluate data and make predictions based on analysis of that data, and justify their opinions based on data they have gathered. Students are asked to make and explain models, to ask and evaluate their own questions, develop methods to solve problems, and reflect on their choices in class.

High school students are in a unique transition period of personality, habit, and brain development. This is an incredible opportunity to help them shape their brains into critical thinking machines. Engaging the many different ways humans learn by using the brain's many pathways for information input is essential to growing those pathways for a nimble brain. Giving students time for reflection on their learning is crucial to self-awareness and metacognition, which is the crux of improving brain function, and increasing learning capacity. Science concepts also are inherently about experimentation and chemistry lends itself very well to hands-on learning, so lectures do occur, but they are the least engaging teaching strategy, and thus not my primary teaching method. I have included a vocabulary word list for this unit, because they are endlessly helpful for both teachers and students.

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Student Reading List

Coconut oils soap recipe. http://www.mommypotamus.com/how-to-make-pure-coconut-oil-soap-for-cleansing-and-laundry/

Food Additives (Lake food dye) http://www.foodadditivesworld.com/lakes.html.

Lake Pigment and paints blog. Sunsikell. https://sunsikell.wordpress.com/.

Making Oil Colors. http://kremerpigments.com/blog/making-oil-color. Recipes for lake pigments in oil.

Making Color Video. http://www.nationalgallery.org.uk/channel/making-colour/.

Materials For Classroom Use

- Vocabulary Word List (included below)
- Highlighters : 3 colors per group
- Index cards
- Water balloons
- Red & blue dry erase markers
- Molecular model kits (gumdrops and toothpicks can be substituted, or this activity can be omitted and only balloon models done)
- Molecule type chart (polar, non-polar, ionic)
- Electronegativity chart
- Beakers, oil, water
- Firm refrigerator magnets (not flimsy and not neodymium)
- Nitrile gloves
- oil, alcohol, water, salt, sugar, and petrolatum (petroleum jelly)
- small beakers, stirrers, or whisks or metal forks
- linseed oil, water, pigments, and aluminum potassium sulfate
- oil paint paper or small canvases, paint brushes, non-polar solvent to clean brushes.

Vocabulary Word List:

Attraction

Ionic bonding

Electrostatic

Protons

Electrons

Positive charge

Negative charge

Electronegativity

Atoms

Ions

Octet Rule

Kernel

Valence electrons

Nuclear charge

Nucleus

Coulomb’s law

Periodic Table

Electron shells

Molecular orbital theory

Electron cloud

Probability cloud

Polar molecule

Non-polar molecule

Valence electrons

Symmetry

Asymmetrical

Electromagnetic

Alcohols

Aldehydes

Carboxylic Acids

Methyl Groups

Solubility

Miscible

Miscibility

Protein

Emulsifier

Surfactant

Hydrophobic

Hydrophilic

Lye

Pigment

Diffuse

Paint

Lake paints

Appendix: New Haven District Standards: (State, National & Proposed National)

New Haven Public Schools requires science teachers to use Connecticut state standards, with an emphasis on inquiry standards, but encourages teachers to consult current national standards that the state derived theirs from, and the likely to be implemented Next Generation Science Standards which have been proposed but not yet approved by the state. This unit is designed to have students practice and evaluate student inquiry skills.

CT SCIENCE DINQ 4: Design and conduct appropriate types of scientific investigations to answer different questions. [18]

CT SCIENCE DINQ 6: Use appropriate tools and techniques to make observations and gather data. [18]

CT SCIENCE DINQ 8: Use mathematical operations to analyze and interpret data, and present relationships between variables in appropriate forms. [18]

CT SCIENCE DINQ 9: Articulate conclusions and explanations based on research data, and assess results based on the design of the investigation. [18]

CT SCIENCE DINQ 10: Communicate about science in different formats, using relevant science vocabulary, supporting evidence and clear logic. [18]

CT SCIENCE 9.2: The electrical force is a universal force that exists between any two charged objects. [18]

CT SCIENCE 9.4: Atoms react with one another to form new molecules. Atoms have a positively charged nucleus surrounded by negatively charged electrons. The configuration of atoms and molecules determines the properties of the materials. [18]

NEAP P12.1: Differences in the physical properties of solids, liquids, and gases are explained by the ways in which the atoms, ions, or molecules of the substances are arranged and the strength of the forces of attraction between the atoms, ions, or molecules. [18]

NEAP P12.23: Electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel. The strength of the electric force is proportional to the magnitudes of the charges and inversely proportional to the square of the distance between them. Between any two charged particles, the electric force is vastly greater than the gravitational force. [18]

NGSS HS-PS1-3: Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. [13]

NGSS HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. [Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.] [13]

NGSS HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. [13]

NGSS HS-PS3-5: Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [13]