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Experience-based Chemistry in a New Era

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Thirty years ago when I took AP Chemistry, I cannot remember ever having a lesson in Chemistry. What theory I had was given standing around the front bench. Theory was explanation to justify why we were doing the laboratory work for that day. There were no chairs or tables, except for the electronic balances kept behind panelled glass. Coming back to High School, we have come full circle. Labs are the explanation to justify the paper work and theory for the lesson. Previously I had never thought of chemistry as theoretical—but it was the hay day of kitchen chemistry when photographic memories were a blessing. What I learned then is hardly in the books anymore. Memory plays a small part. Chemistry is more like Physics—theory learned with mathematics.

Chemistry was exciting and dangerous even if poorly understood. Now its danger is recognized as more insidious and liability incalculable. Contemporary intellectual elegance in Chemistry and technological advances has streamlined and made redundant the endless chemical analyses and titrations of a former era. However I feel we are left with a crisis. The swing from kitchen to computerised chemistry has emptied the emotionality, motivation and drama from Chemistry.

Here is not the place to take up the implications fully, but the purpose of this unit is to address part of the issue of motivation and emotionality. Currently what was once called physical chemistry is now center stage and all but defines Chemistry. Its theoretical elegance seems lost on my students but may be this could be changed if it could be taught in the context of the great crisis and drama of our day and age—the struggle to preserve the biosphere. Water Chemistry, solubility, atmospheric oxidation/reduction, environmental acids/bases, salts, toxic elements, fuel hydrocarbons and so forth could be the context in which core chemistry can come alive. Rather than teaching environmental chemistry as an extra, in the line margins or in pretty boxes in the text, one puts it into center stage from which to justify physical chemistry or inorganic chemistry. The laboratory becomes the natural elements of environment, water, air and earth from which the theory takes shape for the student.

The idea is to take existing divisions in typical High School or University texts but instead of letting the environment (or other issue/context) be the application or illustration of the theory, let a study of the environment etc., raise the issues that cause us to look at theory—just as a teenager, I took a break from lab work to appreciate theory. Rather than the environment, we could equally begin with new inventions, products on the market, local firms and enterprises, chemicals used in the home or in the pharmacy or on the street. To some extent this is achieved already in undergraduate courses in Environmental Chemistry, but the focus

even in Manahan's excellent book, 'Fundamentals of Environmental Chemistry', is on creating a separate field of study rather than on addressing the pedagogical issues in teaching General Chemistry. The following unit is an example of contextual chemistry with a difference in that each class is structured by an open-ended experiment and the units are designed as a simulated journey through a real world situation. In this case I have chosen the Hydrological cycle and follow an imaginary water molecule as it moves from ocean to sky to earth and encounters with 'civilization' before it returns to the sea. Each class is divided into a pre-lab (coming up with a hypothesis to test), a lab (students design an experiment to test the hypothesis), and a post-lab discussion (students integrate theory with their findings). The initiation is a discussion in which students talk about what they already know about the problem of the day. Relevant bites of theory are introduced. An aspect of this is offered to the students to test. The suggested experiments are intended to be mini-labs that can be performed in a single or double 50 minute class session. By tying in problems, ideas, experiment, conclusions and theory into a single session, each class becomes relevant, experiential, hands on, analytical, contextual, student centred and theoretical.

In the first instance I was motivated to devise this unit to teach chemistry that was interesting to me as teacher, to help recapture for students the love of chemistry that I had gained in a former time and place but that now seemed jeopardised by the inexorable march of 'progress', and to find a way to give meaning to chemical theory without it being intimidating to students in the normal everyday range of ability and intelligence. In this latter respect I was helped by the SESAP theories of teaching science, but also from my own philosophy of education centred on the dictum that 'experience teaches'. The following unit therefore seeks to exemplify four pedagogical truths that I believe to be self-evident and critical in devising any successful chemistry course.

A.S. Neill in 'Hearts not heads', provides my first proposition that feeling awareness (experience) is prior to meaningful cognition. Mind, from birth onwards, can only find order from within experiences previously given by our feeling senses. Mind is otherwise empty abstractions or conditioned responses (as in brain washing). Textbooks can describe other people's experiences and with empathy and imagination we can to some extent enter into their mind sets. In chemistry where we are learning about the behavior of matter, we need to recapitulate journeys of exploration of former scientists or enter into simulated journeys of discovery. The aim is not to learn facts but for the mind to find a meaningful order within a multi-dimensional experience.

My second proposition is given by Nietzsche. He was deeply opposed to reducing reality to a web of self-consistent logic. Truth is essentially fragmentary and is only grasped as we continuously subject it to experience. The mode in which theoretical chemistry is presented is as if reality consists of mathematical theorems of which chemistry supplies examples. We are lulled into believing that there is such a thing as a mechanistic metaphysic with absolute laws constituting the bedrock. Chemistry is then a closed book or bible upon which the outer edges are gradually being filled in by scientists to provide the actual constitution of reality. In theory at least, one day there will be nothing more to be known. The consequence for the class room is to turn teachers into catechists and students into learners of sacred scientific scripture. Ironically, science has been turned on its head by its own success. We can correct this by teaching it in the manner by which it gained its success, i.e. by subjecting mind always to experience.

Something of course is being built up in the grand edifice called science. For Robin Barrow in 'An introduction to the philosophy of education', it is a body of knowledge agreed upon by a professional caucus of experts. A student is initiated as neophyte and the teacher guides him or her through the curriculum given by the academy. In the sense that experience is always mediated through culture (language belongs to culture, not to an individual necessarily), Barrow's views are profoundly true. Culture, like mind, is no less bound to the

need to be subject to experience. The problem with raising curriculum to such an exalted position, (as is typical in the classroom), is that the student is not really allowed to think until at the end of the exercise. Only once we are brainwashed are we safe to ask questions. The resolution of our problem is to see the relationship of individual experience to corporate experience as a dialectical one. The teacher, as representative of the academy and the student as neophyte, are both confronted and subjected to the universe of experience. The teacher acts as a guide and in conversation with the student along the way of simulated experience such as experiments, a cathedral of thought is built up. The foundation, however, is not the academy or textbook, but experience generated in the classroom or field exercises.

It is basic to my theory that the central event in an instructional event is an experience that is inviting to the student and an experience from which the student can learn. Contrary to popular notions, science is not about objectivity. It is about finding explanatory models (the subjective pole) that best fit experience (the objective pole) so as to build up knowledge (science). Science does not allow mere private experience but it is only through private experience that we can make connections to public domains of experience. Subjectivity turns into objectivity once others confirm our grasp of experience by reproducing the events and findings. No amount of accurate use of SI units makes anything more objective -units are arbitrary, relative and based on convenience. It is their use in describing what happens in an experience that enhances objectivity. As we all know, however, experience cannot be taught. It is something that teaches us. Hence the style of these classes are open ended. Experience is the best teacher.

Introduction to the journey of water through the hydrological cycle.

Without the hydrological cycle, our planet would be unrecognisable. The cycling water from liquid to gas to solid in the troposphere and down again to earth as rain, cycles innumerable substances essential to life. Water, of course, is the cradle of life, but just as important to life, is the catalysing effect of water that makes essential chemistry possible. It is the peculiar property of water's hydrogen bonds that pulls ions out of crystalline structures so that reactions occur that otherwise would take 1000+ degrees Celsius to happen.

The solubility characteristics make it the popular 'universal' solvent. It is its crucial solubility qualities with carbon dioxide that enable it to buffer body pH, soil pH and which combined with its solubility characteristics with oxygen, enables respiration to occur. In this way, it is water that we live, move, breath and have our being in.

The hydrological cycle rapidly turns at the earth's surface, some what slower as it seeps through soil, rocks, caves and along the water table down to the rivers, lakes and oceans. There is a yet slower journey that occurs in geological time at the polar caps and in the lithosphere where water is seemingly locked up indefinitely in combination with covalent and ionic compounds, in water of hydration and rock crystalline structures.

Mammalian interference, notably by Homo sapiens, has impacted some of that journey. By dumping toxic substances we have also threatened the hospitable aspects of the cycle chiefly by undermining the capacity of the cycle to keep the environment safe for life. Civilizations in the past have risen and fallen by movements of the hydrological cycle. If we do not learn from the hydrological cycle, our civilization will bite the dust literally and figuratively. Water waits for no man. (Horne 78)

The following nine lessons follow water on some of its convoluted journey through the hydrological cycle. Along the journey, we try out some explorations to see what water is up to. We follow it up from the ocean to the clouds, down through the air to earth, percolating through soils, entering into rocks and bodies, into our houses, dripping through rocks, passing over roads, into sewers, down to dumps, to lakes and rivers and back to the oceans. Our journey is diagrammed below.

I. FROM OCEANS TO CLOUDS

Why is it so pleasant to sun bathe by the ocean? Why does the sea seem warmer than air in the evening and colder during the day? Is it illusion or real? Why is the ocean salty yet the water that evaporates to become rain again in the clouds has no salt in it? How is it that solid water in the form of hail and snow falls to the ground yet floats on water, when we all know that solids usually sink in liquids? Since leaves on a tree have a massive surface area and through transpiration evaporate water into the air in great quantities, how can trees be said to help preserve soil that needs that water? Where does the energy come from that cycles the huge amounts of water up to the clouds and why do the molecules stop at the clouds and not just keep going up higher and higher? Why does water rise and then fall down again? These and many other questions might be on the minds of youth and as such questions are probed, some of them might just register as significant because this stage of the hydrological cycle is a common enough, if not daily experience. Making sense of experience is what science and education have in common. What we cannot immediately experience, we can simulate through experiment. Hence ideas that come from our discussion need to lead to an exploration. Some of the students' ideas can be expressed as hypotheses and an experiment planned.

A possible plan:- We want to find out what happens when we heat polluted water. In the process we might want to measure the boiling point of the mixture, collect distillate, cool it, supercool it, and out of curiosity, see what happens to supercooled water when a polluting particle is added to it.

A possible design of an experiment:- Use copper sulphate since it is a colored salt solution and the salt is obviously left behind (as in the sea) as the distillate is colorless. Devise a simple boiling apparatus from which steam can be lead into a clean cooling flask that in turn can be readily super cooled. Only a small amount of distillate is needed in a conical flask. Immersed in a mixture of salt and crushed ice-cubes (as in making ice cream), the water can be supercooled (if not shaken). Adding a particle of dust may well cause dramatic sudden freezing of water at a temperature well below freezing.

(figure available in print form)

Reporting results:- The value of this experiment is in its use as a model of the short hydrological cycle. It has limits to its value but students can learn by talking about what they did and comparing and contrasting distillation and supercooling water in the class room to the process of solar evaporation and formation of snow, ice and rain in the clouds (see lesson plan below)

II. CLOUDS TO SOIL

Rain dissolves carbon dioxide in the air to form carbonic acid, an acid not unlike vinegar in terms of behavior and strength. Much smaller amounts of sulphur dioxide and nitrogen dioxide are dissolved in the air over cities where coal and cheap fuels are burned in incinerators, power plants and engines that have no catalytic converters. Dilute but strong acids such as sulphuric and nitric acids rain down to dissolve buildings, statues and sadly our lungs. Out on the hills and mountains, acids carried into the lower atmosphere come down again as acid rain, usually hundreds or thousands of miles from where they were produced. As in the Smoky

Mountains, trees may die, but not all lakes are polluted as badly as might be expected. Fish continue happily swimming because as the water trickles or percolates through the soil to the rivers that supply the lake, something acts to neutralize the acid. Before we look for this possible something, we need to understand a little about acids. Pure water is partially ionized into equal numbers of hydrogen ions (protons, what lightning is made of) and hydroxyl ions (what bases, other wise known as alkalis have that are important for neutralizing and making hydrogen ions safe). The salts of the alkaline earth metals, especially calcium and magnesium commonly found in soil as chalk and so forth, are good at chemically disposing of hydrogen ions in the form of acids.

Planning or hypothesis making:- Which kinds of soils could be best added around lakes to help neutralize rain as it seeps down to the water table and off to lakes? Easily obtainable from the stores are potting soil, limestone, sand, gravel and more easily still, local soil samples. Which soil or combination of soils is most effective?

Exploration: Designing an experiment using colorless vinegar as a substitute for carbonic acid is perhaps easier than making ones own acid rain. A simple demonstration of the acidity of breath is for students to blow into dilute BTB that will quickly turn yellow -indeed can do so just by being left uncovered over night if the air is at all acidic. Using color coded pH strips, it is easy to test acidity of vinegar before and after pouring it through soil samples and collecting it in run off cups. Playing with mixes of soils and guessing probable outcomes is important in the design of the exploration.

Reporting outcomes:- Apart from discussing the chemical reaction in limestone and in potting soil, the experiment introduces the variable of percolation rates that may alter expected acidity outcomes. The experiment raises the question of accuracy and reliability of using small numbers of samples and the accuracy of pH paper. This experiment is described in various recent biology texts and was used essentially in this form in the Connecticut Aptitude Test in Science for 1994, (see lesson plan below).

III. ENTERING ROCKS AND OUT AGAIN

In the formation of rocks, water enters into the crystal structure of the mineral, but itself does not affect the chemical properties of the rock. We call this water of hydration. Much more importantly, as rocks crumble into powder and dissolve into solution, water again plays an important role but does not affect the chemical outcome. In this instance water plays a catalytic role. Chemical reactions occur that would otherwise require huge temperatures. The hydrogen bonds not only pull elements out of their crystalline form, but in the process distance positively charged ions from negatively charged ions. The ions freely move around and now can carry electrical currents. Metal ions and their salts that do this in aqueous solution are called electrolytes. Some readily are separated apart by water and as such are called strong electrolytes. Some substances do so only weakly -weak electrolytes—and some do not do so at all -nonelectrolytes. Why should water have this power to separate ions and so facilitate or catalyse chemical reactions? Why is it that some substances are vulnerable to water and some not? In a later exploration we can look more closely at hydrogen bonds, but we can learn just by sorting out a variety of compounds into electrolytes, nonelectrolytes and weak electrolytes and then see if this suggests an answer. We can also check out if water really does have this power by contrasting solid and dissolved substances such as salt, bicarbonates, sulphates and so forth.

Plan:- Students can choose a variety of substances, including some minerals or crystals that can be ground down to powder and then dissolved in water. The equipment to test for ionization can be cheaply bought. Radio Shack and other electrical outlets sell oblong batteries with snap attachments for a wire that can lead to a tiny Christmas tree light socket and bulb with continuing wire, and plastic covering stripped off to act as an

electrode. At the other pole of the battery another wire leads by snap on attachment that can act as the other electrode. The two wires can now be dipped into drops of solution or in well plates to see if the circuit can be completed as indicated by the light coming on. If it lights weakly or bubbles show between electrodes with no light, the solution is a weak electrolyte. A bright light indicates a strong electrolyte and none means that ions have not been pulled into solution by water.

Exploration:- Making the equipment in groups (cheaper and better learning experience), making out recording charts, discussing how to solve technical problems which easily arise and predicting results using the periodic table (only metal salts form electrolytes and semimetals are uncertain) makes this exploration particularly interesting and a constructive experience.

Reporting:- Students can lead the discussion on results and conclusions. If they have a background in the periodic table they may raise some theoretical ideas (see lesson plan below—also small scale lab manual—see bibliography).

IV. IN THE BATH AND KITCHEN

The session could begin with a discussion of cleaning up oil spills and why soapy water is effective. Oil does not mix with water, but under certain conditions it appears to do so. To explain this, it is time to discuss hydrogen bonds.

Very simply put, there are two kinds of ways in which elements join together to make compounds. In one kind, the atoms join like jigsaw pieces. Electrons orbiting on the outer valence shell may enter into a vacant orbital in a neighboring atom. The electrons are now shared and held in that orbital by the effects of positively charged protons in the nuclei of both atoms. The distance and angles of the 'jigsaw piece' bond is very precise, as a rule, but other factors can come into play, as is the case in water. Because there is only one electron spinning around one proton in hydrogen, the attractive power of the oxygen nucleus with 8 protons is enough to pull the hydrogen's negatively charged electron way over into the oxygen electron orbitals. As a result the two hydrogen protons in water are somewhat bare and have an exposed positive charge. The water molecule is now turned into something of a magnet (actually electrostatically charged particles but it is easier to visualise the pull of magnets). The scientific word for this 'magnetic' pull is ionic charge. Water thus enters into covalent (jigsaw) type bonds and ionic (magnet-like) bonds, though the latter is much weaker. Because it is about as half as strong and due to the smallness of hydrogen and the resulting skewed shape of the water molecule, the ionic bonding is instead named hydrogen bonding. The hydrogen bond can be used to pull metals out of crystalline structures or cause water molecules to pull on each other in such a way to make it much harder to evaporate than other comparable small molecules. It also means that at exposed surfaces to air, water molecules are pulled back into the liquid such that we have drops or globules of water on the shower walls. Soaps have the odd effect of neutralizing the hydrogen bond effect because of their long molecular size, but it is this long size that enables soap to surround oil droplets and have 'surfactant' qualities of soap on water to change surface tension and enable oil to sink in water. The phenomenon can be explored in a simple experiment involving soapy water and tap water.

Plan:- How many drops of water can one separately and independently place on a penny? What happens when we add detergent to the water? What happens if an emulsion of oil and soap are made and added to water?

Exploration:- It is important for students to estimate in advance and to carefully record results and to make statistical counts and averages. The best technique is to tease out the end of a plastic micropipet and drop small drops of solution on the penny without one drop running into the other.

Reporting:- The exploration is only satisfactory with large numbers of repeated attempts until results become consistent. Poor technique introduces huge errors. Students can work this out and in the process get a feel for the nature of hydrogen bonding.

V. BUBBLING THROUGH ROCKS

The underworld is full of dark and surprising places largely left alone except by potholers and caving enthusiasts. Farmers for miles around Mammoth Caves in Kentucky and Tennessee know about sink holes. Garbage can be placed in mudded groves and it always sinks and disappears down into the ground like black holes in space. Nothing comes out that goes in. Underground are enormous caves and underwater rivers, streams and lakes where water may be stored and remain for long periods of time. In the oceans where most water is stored in abyssal plains, the predominant ion is sodium, but in fresh water lakes and underground reservoirs, calcium and magnesium predominate. The concentration of ions and salts depends on the nature of the rock over which water flows. In dripping chalky caves enormous stalagnites form from chalk coming out of solution. Sulphates of calcium and magnesium also are deposited. Water with these sulphates form permanent hard water that can only be chemically treated or passed through ion exchangers (sodium ions exchanged for calcium or magnesium). Soap achieves the same purpose but leaves scum. Temporary hard water can be treated just by boiling, but the carbonate precipitates out to form scale in pipes or water heaters. The measure of hardness of water is determined by the readiness with which bubbly froth forms with soap or detergent. Since the use of water for cleaning purposes is so important to us, it is useful to determine the hardness of local water and to determine how best to soften it.

Plan:- A variety of different water hardness can be achieved by dissolving in salts of calcium and magnesium. Each of the samples can be tested for their hardness, including local tap water, by treating with a variety of softeners. Samples can be boiled or unboiled.

Exploration:- An initial approximate guess can be made using soap solution quantities estimated by measuring out five ml quantities at a time and then shaking the given volume of test water. When a centimeter of froth forms, the water has been softened. Once a rough titration point has been achieved the procedure can be repeated using micropipet measured quantities and great care taken close to the point of softening. In this way it is unnecessary to use the expensive glass measuring burettes.

Reports:- Students as a group can debate their results and work out why differences exist in titrations. Explanation of results can be accompanied by chemical equations.

VI OVER ROADS

In heavy rains, water flows along the roads and then enters the drains to the sewers. Water cleans the air, cars and roads. Heavy rains can be hazardous for driving in because a film of water comes between the rubber and the surface of the road so that the car skids for a short distance in breaking. At higher speeds, the phenomenon of hydroplaning occurs. However none of this compares to the threat of ice on roads to the safety of pedestrians and vehicles in winter. A property of solutions is used to keep ice off the roads—the phenomenon of depressing freezing point by adding particles in solution. The lowering of freezing point is directly proportional to the number of particles in solution. If the substance forms ions in solution, like salt does (sodium and chloride ions) then the number of particles is doubled for every molecule of substance present in solution. The opposite occurs to the boiling point of water. Sugar water boils at a higher temperature than pure water. The depression of freezing point or elevation of boiling point is directly proportional to concentration of solvent added. For every molar concentration of a substance added (the gram

formular mass of the compound divided by the number of ions the compound divides into in solution—2 for salt), the freezing point is depressed by a predictable number of degrees celsius. The more icy cold the weather becomes, the more salt is needed to prevent freezing of water on pathways. Because the depression of freezing point is precisely predictable, gram formular masses have been calculated for molecules—but here we need not concern ourselves with that aspect of solutions.

Plan:- Students can determine the gram formular mass of salt and calculate the mass needed to dissolve in 10 ml of water so that the concentration is a 1 molar solution. A 1, 2, and then 3 molar solution of salt water can be made up and the results of freezing depression for each concentration can be plotted on a graph. The proportion sign between moles concentration and temperature can be converted to an equal sign when the slope of the graph is determined (i.e. the constant for water as solvent).

Exploration:- Regular thermometers only register down to minus 10 degrees Celsius but since one mole of salt has two moles of ions and the freezing point depression is just under 2 degrees per mole, students can come up with three points on the graph that should go through zero on the graph. With four plotted points, we should have enough to demonstrate colligative properties of salt in water.

Reporting:- Students can estimate the slope of their graphs and determine if the class average is close to text book values. The elevation of boiling point is fun if sugar is used. The boiling point of candy can be estimated.

VII IN SEWERS

Water as it is collected from the sewers is passed along to a sewerage or water treatment plant. Water coming from lakes, rivers and household or industrial discharge will also need to go to a water treatment plant for purification. What kind of pollutants will be present in water that will need to be removed before it is safe and pleasant for drinking? What kind of processes would be needed to achieve this? Treatment falls into three categories—physical separation (removal of solids by settling, sedimentation, coagulation or flocculation, skimming, filtration etc)—biological treatment (using bacteria to remove organic nutrients as in trickling water over bacteria laden rocks and aeration)—chemical treatment (disinfection using an oxidant such as chlorine or ozone etc and removal of discoloring and bitter tasting iron or manganese).

Many kinds of sophisticated methods have been developed to analyse the presence and removal of toxic heavy metals in water. For our purposes we want to perform chemical tests on samples of water to identify significant levels of concentration of common polluting ions. These tests are usually carried out using titrimetric (quantitative) equipment but here we will be satisfied with a qualitative analysis.

A possible plan:- The student's task is to take 5 clear samples of water, each separately polluted by a different ion. Students will conduct tests to identify which ion is in which water sample. Seeing colorful precipitates form and then disappear to confirm a test makes this a popular activity requiring care and helps improve laboratory skills.

A possible design of an experiment:- Students are given the following simple tests for each of the five ions being investigated. The creative part is to come up with a way to organize results since if students do not so they will find themselves confused. The tests require just a few drops of sample and reagents so tests can be conducted on saran wrap covered white paper. The curvature of the drops magnify the precipitate and the white provides maximum contrast and light. Polluted samples can be made up with very small quantities of any colorless soluble compound containing the following ions.

Chloride ion—Form a nitrate by adding nitric acid. Add silver nitrate. If chloride is present, a white precipitate of silver chloride will result that will disappear when ammonia (ammonium hydroxide) is added.

Phosphate ion—Add silver nitrate to a test sample. If phosphate is present, a yellow precipitate of silver phosphate will form that disappears if nitric acid is added.

Mercury ion—With tin(II)chloride, a white/gray/black precipitate forms if mercury is present (HgCl₂).

Magnesium ion—A few drops of a dye (p-nitro benzene azoresorcinol) added to a sample made alkaline by sodium hydroxide forms colorful complexes. It will be sky blue if magnesium is present.

Lead ion—A drop of acetate solution and chromate solution added to a sample of water polluted by lead will form a yellow precipitate of lead chromate.

Carbonate—Add hydrochloric acid to a sample polluted with carbonate will cause carbon dioxide to be given off as bubbles.

Reporting results:- Good organization of results and care in conducting tests should lead to general agreement among students as to the identity of polluting ions in which samples of clear water. The greater the dilution of pollutant, the greater need there will be for students to discuss what actually they saw. This is an opportunity for students to write balanced equations to describe the reactions. A discussion can ensue as to what makes these ions toxic or pollutants.

VIII DOWN TO DUMPS

Water as it comes through the atmosphere cleans the air. It can be quite acidic as it enters soil. Surprisingly, water as it seeps through soil, will be perfectly neutralized by the time it reaches the ground water reserves that forms above the rock below the soil. This beautiful resource of well water used to be uncontaminated but besides levels dropping through excessive use, well water is being increasingly threatened by waste dumps. Streams in woods once containing living organisms are disappearing because of indiscriminate dumping by individuals. More serious, however, are city and organized dumps. They can be covered with soil and made to look like little hills but as rain seeps through them, the water pulls into solution all manner of chemicals that concentrate and react together to form toxins. Over time, these accumulate in significant amounts and drain off into the ground water system. If it is a modern dump, there will be a double layered liner. Beneath each liner will be a 'blue cheese' piping network that feeds solutions to analytical laboratories that will alert them of liner tears. Many sophisticated methods are used to analyse mixtures of complex chemical solutions carrying complex solvents. Gas chromatography is one such method but here we will use a traditional chromatogram that demonstrates the principles used. Solvents will separate out as they pass through filter paper -their absorbant attraction to the paper is different and characteristic for each chemical. Fast moving chemicals will leave the slower behind and the paper can be cut out with the separated chemical that can then be tested. Alternatively, if tests have already been devised, the relative position of a solvent in filter paper as it travels up, since it will always find that characteristic position, identifies the compound. This is most easily done when colored dyes or solvents are present.

A possible plan:- Students can extract dyes from candies, leaves, pens and certain kinds of cloths by grinding them with a mortar and pestle and using a suitable solvent—water, alcohol, acetone (use a small quantity since very volatile!). Students can also be given dyes of known chemical composition such as cooking dyes. The idea is for students to make chromatograms of unknown dyes and compare them against known dyes to

see if their position and color on the chromatogram can be used to identify the unknowns.

A possible design of an experiment:- Making good chromatograms takes considerable care, however they are not difficult and for our purposes, only approximations are needed. The easiest experiment is to provide three known cooking dyes of one color and then an unknown that is in fact a mix of two of these dyes. When small dots of sample dyes are placed along a pencil line drawn horizontally near the bottom of filter paper and spaced an inch apart, one percent salt solution will travel up the paper when dipped in such a solution. Care must be taken that the sample dots of dye are above the water line of the salt solution. As the solution rises it separates out the dyes to different vertical positions on the paper that is characteristic for that chemical.

Reporting results:- One percent salt solution is better than isopropyl alcohol because it is faster in traveling up paper and so the experiment can be concluded in one lesson. If the lesson is carried over to the next day, a slower solvent can be used but one has to make sure that the paper does not stay too long in solvent or else all the dyes may well be washed out and there will be only disappointment when it comes to discuss results. The main topics of discussion is good technique and how technique affects the accuracy of results. Allowing students freedom to come up with the fine details of procedure enables them to learn from their mistakes and successes. Repeating the experiment is also good form.

IX TO RIVERS, LAKES AND BACK TO THE OCEAN

One of the critical events on the way back to the sea may be thermal pollution especially due to power plants (extensive discussion in Horne, p460 ff., see bibliography). Vast quantities of water are heated, used for power source and returned to rivers or estuaries. The temperature of water may increase by as much as 10 degrees Celsius. The chemistry of water changes considerably and most significantly by affecting the solubility of oxygen. Larger fish will die due to oxygen depletion but crustaceans such as lobsters in estuaries may benefit.

A possible plan:- The inverse relationship of temperature to solubility of gas can be demonstrated by students using up-turned test tubes full of cola and dexterously lowering them still full of cola (preferably diet soda since regular sodas are sticky to work with) into a beaker of soda. The cola or soda bath is then slowly heated and the volume of gas above solution in the test tube is measured as it increases in size with increase in temperature. A can of soda per group of students is sufficient. It is best to use a gentle source of heat or the temperature will rise too fast. Since this is a safe and relatively easy experiment, students only have to understand the idea of the experiment to plan it themselves.

A possible experiment:- The student's task is to plot a graph of changing volume of gas to changing temperature. The experiment can be repeated with no source of heat as a control for the loss of gas that would naturally occur due to Henry's Law (i.e. gas becomes less soluble with decreasing pressure above the solution). Comparison between graphs gives the effects of thermal pollution. The graph, in fact, models oxygen depletion exactly as it occurs in rivers due to thermal pollution.

Reporting results:- The more reflective student may realise that the shape of the graph is not as simple as would be expected, i.e. the graph is curved and not straight indicating another factor at work. Why does the rate at which carbon dioxide is given off decreases as temperature increases? If the relationship of solubility to temperature is direct, it should be less dramatically curved at the top end. They may come up with the answer that initially there is plentiful gas but as the temperature rises the scarcity of gas affects the quantity given off so the graph will tail off reflecting the depletion of gas in solution. This experiment is a good one for demonstrating the importance of a control in experiments.

MATERIALS

The most basic requirements, per group:

Household items—Pennies, variety of coins, spoons, tape, lollipop sticks, sterile pads, scissors, thin and wide straws (one fits in the other, to be used as substitute for glass tubing), Christmas tree light bulb, socket, wire, clips or solder, battery, paper cups, paper towel, liquid soap, three medium sized beakers and a measuring cylinder, thermometer, clock with second hand, accurate plastic micropipets, filter paper, chalk, cooking dyes, can of soda and bottle of vinegar.

Chemicals—Copper sulphate, magnesium sulphate, dilute nitric acid, dilute hydrochloric acid, soluble compounds of chloride, phosphate, mercury, lead and carbonate ions, silver nitrate, ammonium hydroxide, tin(II)chloride, and acetate and chromate solution, and if possible, the dye p-nitrobenzene azoresorcinol.

CONCLUSION

The original problem that this teaching unit set out to solve was how to address the student's need for intrinsic motivation to studying chemistry and at the same time to introduce students to theoretical chemistry. The needs of the academy must be balanced against the needs of the students as novices. The balancing act is the art of teaching. Elegant displays of theory in beautiful text books with lavish color photography and applications to the real world and careers is, in my view, insufficient. Chemistry continues to appear to be terribly abstract and flunks out poor students with the greatest of ease. Going back to the days of kitchen chemistry when this was not so, is not an option, not merely because it was expensive, dangerous and environmentally irresponsible, but though it wonderfully motivated students, it suffered from excessive mindless description signifying very little. The Linus Pauling revolution that put theory into the heart of the syllabus has given order but has thrown the baby out with the bathtub from my point of view as teacher. Does the above pedagogy of experience-based chemistry using an analysis given by the scientific method in terms of learning theory do better?

Clearly the strategies outlined above are only a possible exemplification of what could be done, It is limited to one particular context that in itself could be used to teach more theory in high school chemistry. Much more could be made of the opening class, 'From oceans to clouds'. There is no discussion of rates at which water molecules move in the hydrological cycle, especially as water evaporates off the ocean. Calculations can be made from experiments conducted in class. For the most part the choice of experiments and theory explored has been dictated from the standard curriculum in Chemistry.

One important way this unit could be adapted is to make it more intentionally interdisciplinary. The hydrological cycle is taught in biology, environmental studies, earth sciences and possibly as a context for mathematics and physics. The academic interests of these disciplines would open up the unit and create new emphases that would dictate the inclusion of many more interesting explorations.

A criticism that I would expect would be that the mini-bites of theory used are truly that—very small, or that in some instances, theory is presupposed (for example the class on sewerage treatment and analysis of ions). To counteract that objection, I would point out that the unit presupposes an introductory unit in which the basic language and core concepts of chemistry have been introduced. One cannot teach hydrogen bonding even in the simplistic way taught here, without having dealt with the structure of the atom. On the other hand,

students do not remember the language of chemistry without continually using it. The scientific method cannot be taught in the abstract. It can only be acted out for it to really mean anything—hence my contention that we need to make it central and not extraneous to the manner in which chemistry is presented. If less theory gets covered, so be it, but actually I think the opposite happens. Once the content of chemistry is introduced in the manner used in the above unit, it enormously speeds up both the understanding of the content, and why it is included in the syllabus and it makes application in problem solving that much easier. This unit must be used as part of a complete syllabus in which key concepts in chemistry are continually recycled throughout. Making sure one is not out of step in the development of concepts is part of the skill of teacher planning.

In the final analysis the proof of the pudding is in its eating. From this teacher's point of view, it dramatically raised the level of active and ready participation from the students. Since I introduced the method towards the end of the year it was not easy to have an overall perspective on success. I had frustration in getting students to hypothesize along with me. It was hard to wean students from following ditto sheet instructions for labs. The last of the experiments on thermal heating I made up in my head and I really did not know what to expect. All of the experiments otherwise are adaptations of remembered experiments from the past or simplifications of experiments, for example, of those in the textbook lab manual. The ideas presented here then are tentative and intended to inspire experimentation in technique of instruction based upon deeper reflection upon what it means to learn from experience in the class room, for both teacher and student.

Lesson plans in Outline

(figure available in print form)

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Annotated Bibliography

Barrow, Robin. *An Introduction to Philosophy of Education*. London, Methuen 1975 Experience-based education is not against curriculum centered education but gently pulls the carpet from under its comfortable conservatism. Barrow's pretentiously written book excludes texts that do not fit in with R.S. Peter's philosophy of the curriculum.

Dewey, John. *Experience and Education*. NY, Macmillan 1963 Americans seem to have wiped from their collective memory their own greatest of all philosophers of education, John Dewey. The ideas succinctly expressed in this short book on experience-based education are not quite the same as those worked out in this unit, but they are consistent with them.

Horne, R.A. *Chemistry of the Environment*. NY, Wiley 1978 In most texts, the hydrological cycle is included as one datum among others. In this major text, the hydrological cycle is the datum upon which the rest of life hangs.

Manahan, Stanley. *Fundamentals of Environmental Chemistry*. Michigan, Lewis Publishers 1993 Though currently a standard text on environmental chemistry, nearly half of the book is given over to a turgid summary of general chemistry. He does this because he knows his students have poorly mastered introductory concepts. From the perspective here, he would more effectively have retaught these concepts by using the environment as a context to bring these abstractions to life, as per this teaching unit.

Neill, A.S. *Hearts not heads in the School*. London, H. Jenkins 1944 Neill is best remembered as the exponent of Free Schools. He wrote prolifically but each book really just develops some part of his theory of education, the most important of which (in my view), is the belief that feeling awareness must precede cognitive analysis.

Wilbraham, Antony. *Chemistry*. California, Addison Wesley 1993 I chose this book as the student text because it beautifully represents the best of contemporary texts on the market. What is wrong with it is what is typical, i.e. theory not context centered. The key concepts found in this unit were taken from chapters 15 and 16 on Water and aqueous systems and Properties of solutions. Ideas for the experiment on electrolytes were taken from the accompanying small scale laboratory manual for this text.

Wilbraham, Antony. *Chemistry*. California, Addison Wesley 1993 A good reference text book for when the basic ideas of the chemistry of the hydrological cycle are understood.

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