How To: Incorporate Green Chemistry Concepts and Activities into a Year-Long Chemistry Course

This document is to be used by teachers to help in the planning process of an introductory year-long chemistry course.

This document is intended to be used to infuse Green Chemistry into a regular Chemistry course at the high school level. A teacher should use this document to augment their established curriculum and replace laboratory activities that use and teach techniques and materials that are hazardous to human health and the environment. The topic areas are those typically included in a high school introductory chemistry course.

This curriculum mapping document was created by a team of high school teachers in conjunction with Beyond Benign staff who surveyed the available materials on the web and in print. The majority of the activities and lesson plans are taken from the Beyond Benign website materials as it is the largest repository for such materials but the team also took an in-depth look at other existing materials. The team focused on true ‘Green Chemistry’ pieces which focus on both teaching green chemistry and on making the chemistry lab less hazardous. Materials that were designed to lessen the amounts of chemicals used i.e. microchemistry were not the focus. (If the credit reads “Beyond Benign” then the materials can be found on the High School Beyond Benign website page at http://www.beyondbenign.org/K12education/highschool.html)

Beyond Benign creates these materials solely for the purpose of supporting the work of teachers and provided resources and no cost. You can help with this process by using the resources and also providing feedback to Beyond Benign if you have changes or additions. We have many teachers using the lesson and labs included here so if you have any questions please contact us and we can provide you with expert help.

1. Introduction to Chemistry
   
   - **Introduction to Green Chemistry**: two videos that you can use to introduce the ideas behind Green Chemistry.
     
     Video – John Warner: Beyond Benign interview (9 mins 22 seconds)
     Video – John Warner: Intellectual Ecology (36 mins)
     [http://www.beyondbenign.org/greenchemistry/greenchem.html](http://www.beyondbenign.org/greenchemistry/greenchem.html)

   - “Defining Sustainability” Beyond Benign – (5 mins 12 seconds) This is an activity that gets students thinking about sustainability and what it means to them.

   - “What is Green Chemistry – American Chemical Society” – Beyond Benign. This PowerPoint was created by the ACS and gives a broad overview of Green Chemistry.

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2. Measurements and Calculations

3. Matter

- “A small dose of Toxicology” – Steven Gilbert, this is a book and will be most useful to teachers not students. This website also contains teacher resources although none of them are really activities but rather a wealth of background information. [http://www.asmalldoseof.org/](http://www.asmalldoseof.org/)

- “Environmental Impact Factor” – Beyond Benign. This lesson is to introduce the concept of e-factor and how it can be used to evaluate matter.

- “Sea-nine 211 – industry example” Beyond Benign. This lesson highlights presidential green chemistry award winning technology, Sea-nine 211 which is an anti-foulant made by Rohm and Haas and is used to coat the hulls of ships in or to prevent barnacles and sea debris from adhering and creating drag. This technology replaced previously used substances that were known to bioaccumulate and create pollution in the oceans. The lesson includes a PowerPoint which introduces the new technology and a lab component that looks at toxicity through an LD-50 lab and the connection of chemicals and living organisms. The lesson can be used to teach bioassays, bioaccumulation and serial dilutions.

- “Sublimation” Beyond Benign. This lab replaces the traditional naphthalene sublimation lab. Students will observe sublimation (physical properties of matter) and explain the type of change that occurred. This lesson also reinforces temp measuring and mass measuring etc.

- “Solubility” Beyond Benign – Students qualitatively and quantitatively describe the relationship between temperature and solubility for gases and solids. Traditional labs use soluble ionic solids, such as nitrate or chloride salts. The disposal of these compounds has negative impact on an aquatic environment. By switching the solvent to sucrose, we are using a natural product that is benign to the environment.

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“Essential Oil Extraction using liquid CO2” – Beyond Benign. Students explore ways to extract essential oils from citrus fruits and evaluate the methods used against the 12 Principles of Green Chemistry. They also explore phase changes. (* This activity could also be used at the end or beginning of the year because it is very engaging for students. It is also great if you are including a unit on industrial applications of chemistry as this highlights a groundbreaking Green Chemistry technology)

- “Design and Application of Surfactants for carbon dioxide” PPT – University of Scranton. This is background information and reading for the Essential Oil Extraction lesson. The readings here are designed for college-level students but can be used successfully with the high school audience.

http://academic.scranton.edu/faculty/cannm1/general.html

4. Atoms and the periodic table


If you do not have access to this resource you can either download it for free from the NSTA site if you are a member or you can pay 0.99 cents to get this issue.


5. Nomenclature

- “Chemistry of Cosmetics” Beyond Benign. Students look at the materials used to make common cosmetics products. They look at the molecular structure of organic compounds and how the shape of the molecule affects the toxicity and potential health hazards that have been associated with cosmetic ingredients. This lesson is particularly relevant for female students and can really help to capture their interest in an effort to get more female students into chemistry.

6. Chemical Reactions and Equations

- “Reactions Lab” – Beyond Benign. In this lesson students observe reactions and identify the type and products produced in those reactions and compare the reactions for their toxicity using the 12 principles of green chemistry.

- “Chemical or Physical” – Beyond Benign. This lab replaces traditional reactions involving chemicals such as cupric chloride, 6M hydrochloric acid, potassium hydroxide, and copper sulfate. Students will understand the difference in chemical reactions vs. physical reactions using all green materials. The goal is to use observations of different types of reactions to discover common threads, ultimately leading to conclusions regarding evidence of chemical reactions. Students will ultimately learn the difference between chemical and physical changes. The goal of the lab is to dispel common misconceptions; i.e. boiling water is not a chemical reaction.

- “Green Precipitation Reaction” – Beyond Benign. This lesson plan is intended to replace a lab where students determine the percent composition of sulfate in alum by precipitation with excess barium nitrate. In this lab, students will determine the percent composition of zinc acetate by precipitation of zinc carbonate, in addition to other quantitative calculations.

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“The Atom Economy” – Royal Society of Chemistry. University of Glasgow. This lesson introduces the concept of atom economy, then examines the intrinsic atom economies for different classes of reaction and then applies the concept of atom economy to drug synthesis. http://www.rsc.org/images/PDF1_tcm18-40521.pdf

7. Mole Concepts

“Moles, Atoms and Grams, oh my!” - Beyond Benign. This lesson practices the concept of the mole and the calculations involved in understanding how moles are used. This lab will require students to measure/mass/build various amounts of salt, water and copper wire. After completing each task (A – E) the student teams will come up to the instructor to see the accuracy of their calculations. This lab helps to reinforce the principles of Green Chemistry as the materials are used and reused year after year in your classroom.

“Mole of Rice” - Beyond Benign. This is a fun quick activity to add onto your unit about measurement where the students have to consider the concept of the Mole as it pertains to Green Chemistry.

8. Stoichiometry


“Stoichiometry Challenge” - Beyond Benign. This lesson replaces a traditional Aluminum to Alum stoichiometry lab with a greener precipitation reaction of sodium carbonate and calcium chloride. It is used to demonstrate how stoichiometry works, showing that if concentrations and amounts of the starting materials are known that the theoretical yield can be calculated from a balanced chemical equation.

9. Atomic Theory and Nuclear Chemistry

“Electron Transitions” - Beyond Benign. This lesson replaces traditionally used flame test activities which and used nitrate salts of sodium, potassium, lithium, strontium, calcium, barium and copper (II) as well as sodium chloride. The redesigned lab includes acetate salts of sodium chloride, sodium acetate, and potassium acetate and plastic beads.

10. Chemical Bonding and Molecular Geometry

“Green Chemistry, Biomimicry and Intermolecular Forces” – Beyond Benign. Students explore the use of adhesives, intermolecular forces and how biomimicry is being used by chemists to invent greener alternative products. (This lesson has a sequence of activities that will augment
traditional content about polarity and intermolecular forces. There is also a relationship to biomimicry if the teacher is comfortable introducing that emerging branch of science.

11. Gas Laws and the Kinetic Molecular Theory
   - “Climate Change Chemistry” – Beyond Benign. In this unit students consider the chemistry behind the concept of climate change while exploring gases and gas laws. This is a multiple lesson plan unit with many options for teachers to choose from according to the level of the student and the depth of the curriculum requirements in this area.
   - “Determining Pressure, Volume and temperature of gases formed” – Beyond Benign. This lab includes percent composition, density of a gas, and determination of the ideal gas law constant.
   - “The Age of Refrigeration” – Royal Society of Chemistry – University of Glasgow. This lesson examines the issue of replacement refrigerants. The aim of the unit is not to teach about the chemistry of refrigerants but to illustrate some of the chemical, industrial and ethical issues associated with the selection, production and use of refrigerants. The unit covers CFCs, modern compounds used in refrigerants and industrial decision making. http://www.rsc.org/Education/HElecturers/resources/itus.asp

12. Thermodynamics
   - “Synthesis of Biodiesel” - Beyond Benign. Students consider the properties of different oils used to make biodiesel and then make their own fuel.
   - “Enthalpy of Combustion” - Beyond Benign. Investigating the molar heat of combustion of paraffin, compared to soy wax, students will be able to measure the thermal heat absorbed by water, measure the heat of combustion of paraffin and soy wax and calculate the molar heat of the combustion of paraffin. This lab replaces the following traditional reaction. 
     \[ \text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2 \text{ and } \text{MgO} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2\text{O} \]

13. Solutions
   - “Starch Concentration Lab” - Beyond Benign. This lab is a modified version of a spectrophotometric determination of bovine albumin concentration using copper sulfate, and Folin-Phenol. While considered mostly benign, copper sulfate is toxic at higher concentrations. By using starch in place of bovine albumin, and iodine in place of copper sulfate and Folin-Phenol, we reduce the financial and environmental cost of lab reagents and products.

14. Solids, Liquids and Phase Changes
   - “Catalysts and Oxygen” - Beyond Benign. This lab replaces manganese dioxide to demonstrate the effect of a catalyst in a reaction. Students will understand the concept of a catalyst and reaction rates, and how a catalyst can improve the efficiency of a process.
   - “Exothermic and Endothermic” – Beyond Benign. Many teachers use the calcium chloride and ammonium nitrate reaction to show exothermic and endothermic reactions. This alternative method uses a catalase, an enzyme found in nearly all living organisms. Students will perform an exothermic reaction, an endothermic reaction and a change in enthalpy ($\Delta H$) in an endothermic reaction.

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“Equilibrium/Le Chatelier’s principle” - Beyond Benign (lesson plan and video). This lesson gives students an understanding of the concept of chemical equilibrium and demonstrates Le Chatelier’s Principle. Traditionally, equilibrium experiments and Le Chatelier’s Principle are illustrated using the following experiments:

(A) \( \text{CoCl}_4^{2-} + 6\text{H}_2\text{O} \rightleftharpoons \text{Co(H}_2\text{O)}_6^{2+} + 4\text{Cl}^- \)

\( \text{Exo blue} \qquad \text{endo red} \)

This experiment is used to demonstrate the effects of both temperature changes and concentration changes on an equilibrium mixture.

(B) \( \text{Cr}_2\text{O}_7^{2-} + \text{H}_2\text{O} \rightleftharpoons 2\text{CrO}_4^{2-} + 2\text{H}^+ \)

\( \text{orange} \quad \text{yellow} \)

This experiment is used to demonstrate the effects of concentration changes on an equilibrium mixture.

(C) \( \text{Fe}^{3+} + \text{CNS}^- \rightleftharpoons \text{Fe(CNS)}^{3+} \)

\( \text{yellow} \qquad \text{red} \)

This experiment is also be used to demonstrate the effects of concentration changes on an equilibrium mixture. In this replacement, the above materials are replaced by everyday non-toxic materials.

The video for this experiment can be found at: [http://www.youtube.com/watch?v=fBdYL3hlBul](http://www.youtube.com/watch?v=fBdYL3hlBul)

15. Acids and Bases

“Recycling Polylactic” – Beyond Benign. Students learn how to take a renewable product, a PLA plastic cup, and extend its lifetime by converting the cup into a cleaning solution. This is a higher level lab that includes the use of some more difficult materials and procedures but can be done at the high school level. We recommend using it toward the end of the school year when your students have had more lab practice.

“Acids, Bases and pH” – Beyond Benign. Students measure the pH, categorize or group substances from their everyday lives, based on physical properties and observe physical properties of acids and bases.

16. Oxidation and Reduction (electrochemistry)

“Dye-sensitized Blackberry Solar Cell” – Beyond Benign (lesson plan and video) Students consider traditional Photovoltaic solar panels and the inherent issues with their chemical make-up and end-of-life e-waste concerns. Students then create their own solar cell using non-toxic materials and blackberry fruit as the dye, understanding how solar cells are manufactured currently and the green chemistry research towards greener solar energy devices.

“Green(er) Redox Lab” – Beyond Benign. This lab replaces the traditional quantitative oxidation-reduction (redox) reaction between copper solid and aqueous silver nitrate. Typically, this lab is done at the end of a large unit covering types of reactions and stoichiometry. This exercise will be used to show a redox reaction between solid magnesium metal and an aqueous solution of zinc chloride. The students will calculate the theoretical yield and using that information calculate the percent yield.

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“Mercury, Membrane or Diaphragm” – Royal Society of Chemistry. University of Glasgow. This interactive teaching unit is concerned with the different manufacturing processes used to produce these materials. These involve electrochemical cells and, as such, this represents an exercise in applied electrochemistry. Throughout the unit you are required to operate in small groups acting as a design team and are asked to devise the optimum operational arrangement for a particular process. This will require an understanding of the basic electrochemical processes but, in addition, an awareness of economic and environmental issues will also be required. 
http://www.rsc.org/images/PDF1_tcm18-40417.pdf

Enrichment and Project Based Learning Activities

“Lifecycle and Sustainability Analysis” – Beyond Benign. This lesson can be used a project for students to analyze any product or process. There is some detailed research involved and it can be used as an end of semester project or as part of a more extensive research project.

“Paint Activity” – Beyond Benign. This activity is a Project Based Learning concept and could be applied to any experimentation with a product that you would like for your students to try. In this activity your students will be challenged to formulate car paint from vegetables, fruits and other consumables. They will then design a process and test their product against performance and green chemistry criteria.