Blue and Gold Make Green: Green Chemistry at UC Berkeley

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University of California, Berkeley
Topics for discussion

- Sustainability in the curriculum
  - Design approach
  - Examples from Chem 1A and Chem 4
- Sustainability of the curriculum
  - Staffing
  - Support
- Sustainable change
  - Mechanisms for continual renewal
  - Strategies for success
About UC-Berkeley

- **Number of students:**
  - 35,838 students
    - 25,540 undergraduates
    - 10,298 graduate students

- **Undergraduate gender:**
  - 53% female
  - 47% male
About Chem 1A, General Chemistry

- ~1,400 students in the fall
- 3 lecture sections run in parallel
- 45 Lab Sections
- 45 Teaching Assistants

- Service course
- Accelerated Curriculum
  - 1 semester of condensed general chemistry
  - Bonding, equilibrium, thermodynamics, quantum
- Students have 1 semester general chemistry then move on to organic chemistry
Greening Chem 1A

Nov. 2009
- Fateful conversation

Jan. 2010
- News of funding from CA-EPA, DTSC

Mar. – Aug.
- Brainstormed new experiments
- Set up green chem testing lab
- “Hired” 6 undergraduates to help
- Developed six new(ish) experiments
- GCEW!

Sept. – Dec.
- Launched six new experiments!
- Modified procedures during semester as needed

John Arnold
Marty Mulvihill
Our Approach

1. Identify current learning goals of lab
2. Find greener alternatives
3. Use green contexts
4. Explicitly tie in green principles
5. Communicate the improved rigor to faculty
New Chem 1A experiments

- Modules of 3 experiments to be used together or separately

- Biofuels
  - Toxicity assay (radish seeds with fuels)
  - Synthesis of biodiesel
  - Combustion of biodiesel
Biofuels Experiments

- Multi-week modules for research-like experience
- Rigorous chemistry
- Give students a valuable learning context.

Week 1

Ecotoxicity Assay:
• Dose-Response LD_{50}
• Standard Dilution
• Concentration nomenclature
• Data Analysis

-Irv Levy, Gordon College, GEMS

Week 2

Biodiesel Synthesis:
• Balancing reactions
• Density
• Separations

-Amy Cannon Beyond Benign
-John Thompson, Lane College
-GEMS

Week 3

Fuel Calorimetry:
• Heat of Combustion
• Efficiency
• Energy Density
• Mixtures

-Jennifer Trip, Chemistry in Context
Preliminary Assessment

- New experiments were well received by students and TAs
- Survey data indicates students think green chemistry is important
- Timing: early term (Oct.), n = 1,160

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
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<tbody>
<tr>
<td>I believe Green Chemistry techniques and practices are important to modern society.</td>
<td>64.5% (749)</td>
<td>30.1% (350)</td>
<td>3.3% (38)</td>
<td>2.2% (25)</td>
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<tr>
<td>I believe Green Chemistry is applicable to my chosen field or discipline.</td>
<td>24.0% (278)</td>
<td>44.5% (516)</td>
<td>26.3% (305)</td>
<td>5.3% (61)</td>
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Some student thoughts on energy sources

The two reactions above can both be used to generate energy in a power plant. Which reaction would you choose to generate energy? (reaction 1 was coal combustion, reaction 2 was methane.)

<table>
<thead>
<tr>
<th>Reaction Choice?</th>
<th>Explain your reasoning.</th>
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<tbody>
<tr>
<td>Reaction 1</td>
<td>Creating a liquid from a gas would require energy rather than generate it (Reaction 2). However to create a liquid from a solid would generate energy.</td>
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<tr>
<td>Reaction 1</td>
<td>There is much more energy gained in breaking the bonds of a solid and creating gases and liquids.</td>
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<tr>
<td>Reaction 2</td>
<td>Its products are both useful and the reactants are readily available. Also, it produces more energy.</td>
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<tr>
<td>Reaction 2</td>
<td>It does not require as many complicated reactions to create more energy.</td>
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**In my own words Green Chemistry means:**

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<td>Green Chemistry means reducing the use of hazardous materials or materials that are otherwise harmful to our environment.</td>
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<tr>
<td>Creating the most successful reactions with the least amount of reactants.</td>
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<tr>
<td>proper handling and careful disposal of chemicals. Also, careful calculations to ensure that as little as possible is wasted.</td>
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<tr>
<td>chemistry focused on finding ways to conserve energy.</td>
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About Chem 4A/4B, General Chemistry and Quantitative Analysis

- ~200 students
- 1 lecture section
- 9 Lab Sections
- 9 Teaching Assistants
- Chemistry Majors!
- Curriculum is broader and deeper
  - 4A: Quantum, bonding, equilibrium, thermodynamics
  - 4B: Analytical, electrochem, kinetics, chemical biology
- Students do laboratory research projects
New Chem 4 experiments

- Nanoparticles
  - Replace CdS with Cu$_2$O or Fe$_3$O$_4$
    - Chem 4A
    - Synthesis and Characterization
    - Band gap, particle in a box
- Silver
  - Chem 4B
  - Synthesis and Characterization
  - Properties, Ag as antibacterial
  - UV/Vis of *e. coli*, kinetics?
New Chem 4 experiments

- Green Extraction and Chromatography
  - Chem 4B
  - GC of limonene from orange peel
    - Quantitative analysis
      - Internal standard
      - External standard
  - HPLC of thymol from thyme leaves
    - TLC to identify product
    - Quantitative analysis
      - Internal standard
      - External standard

http://www.methodhome.com/
http://www.cleanwelltoday.com/
Example Chem 4 Experiment

How much limonene is in an orange peel?

Greener Extraction:
• Liquid CO₂
• Prepare samples for GC
• Anisole as internal standard

Greener Chromatography:
• Ethyl acetate replaces halogenated solvent to dilute samples

References:
Key factors in success thus far

- **Space**
  - Dedicated testing lab
- **Time**
  - Summer, concerted effort
- **People**
  - Me, Marty, TAs to generate ideas
  - Excellent/flexible storeroom staff
  - Undergraduate volunteers to test/write/revise
- **Money!**
- **Support**
  - Department buy-in/authority to make changes
Dow Foundation, $3.5 million

The Dow Laboratories for Sustainable Chemical Sciences Instruction

- Renovations
- Curriculum redesign for sustainability
- Undergraduate instrumentation facility

“Berkeley CBE alum David Kepler, Dow’s Executive VP for Business Services and Chief Sustainability Officer, assists Dean Richard A. Mathies in removing a wall in preparation for the rebuilding of the college teaching labs.” (CoChem News, February 24, 2012)
Challenges

- Sustainability of the curriculum
  - Despite Fall 2010 roll out, Spring and Summer did not adopt
- Need for administrative support
  - Paperwork
  - Submit grants
- Time to think!
  - Improved green storylines
  - More inquiry driven labs
  - Alternatives to prelabs, lab reports?
Future work

- Greening of Existing Courses
  - Continue to develop suite of experiments for Chem 1, 4
  - Highlight green principles in organic chem (Chem 3)
  - Expand throughout the entire curriculum
- Assessment of student learning of green chemistry
  - Current and changing attitudes
  - Problem solving approaches and reasoning
  - How do we define the criteria for measurement?
Thank You

- Funding
  - Cal EPA: DTSC
  - Dow Foundation
  - Department of Chemistry Stock Rooms
  - Hayden McNeil Publishing
  - Dean Mathies of the College of Chemistry
- University of Oregon
- My colleagues at Cal
  - Marty Mulvihill, John Arnold, Angy Stacy, Bob Bergman, Anne Baranger, Mary Ann Robak
  - Berkeley Center for Green Chemistry