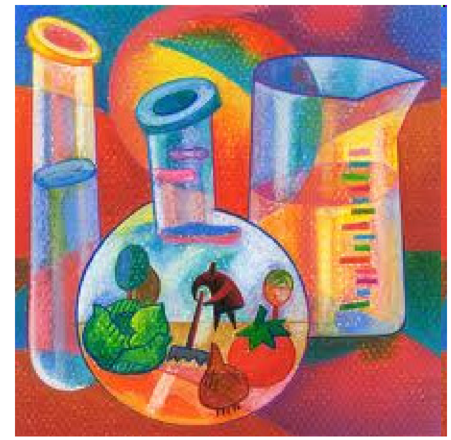
Incorporating the principles of Green Chemistry into Curriculum at UC Berkeley

Marty Mulvihill
October 26th, 2010
Green Chemistry in Higher Education



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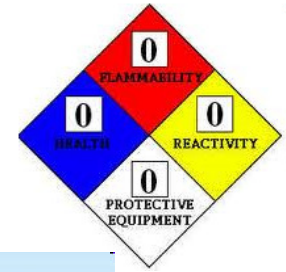
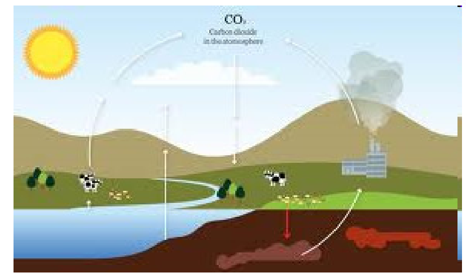
Learning Goals

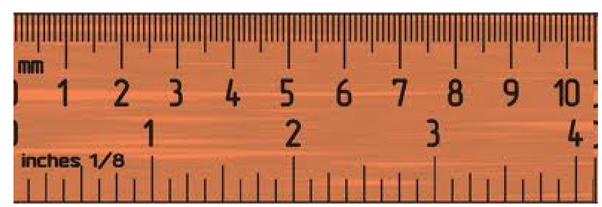


- Identify, evaluate, and minimize the use of hazardous chemicals.

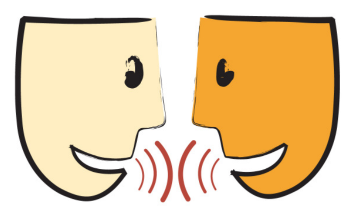


- Understand the origins and the fate of chemicals in the environment.

- Design safer and more efficient chemical reactions and processes.



- Gather data and effectively use both qualitative and quantitative metrics.



- Communicate scientific data and concepts to both experts and the general public.

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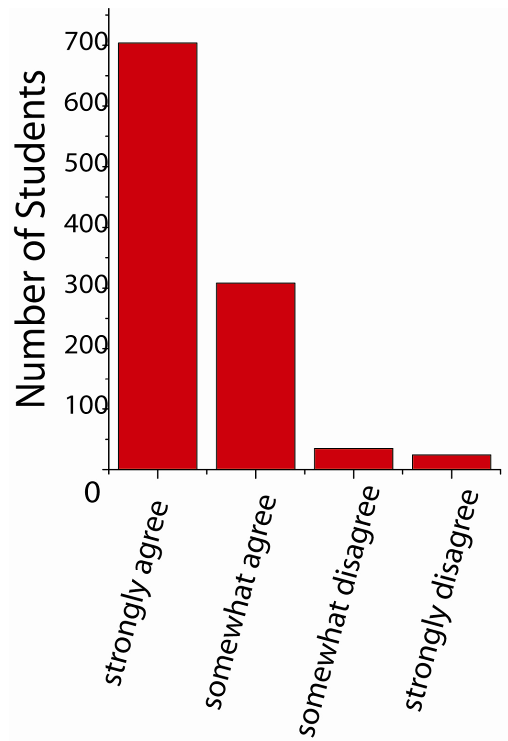
The Vision

Green Chemistry = New Chemistry

- Bio-based starting materials
- Inherently safer reagents
- Discuss environmental concepts

Driven By Students

"I believe Green Chemistry techniques and practices are important to modern society."



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The Opportunity: Introductory Chemistry at UC Berkeley

- 2000 students/year
- 1345 students currently enrolled
- Continuous development by Michelle Douskey and Angy Stacy
- Considering Separating Lab and Lecture
- Dean Mathies would like to modernize and modularize the undergraduate labs.

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The Challenge

Cheaper

- Use existing equipment.
- Stockroom must be capable of supporting the activities.

Safer

- Fits well with Green Chemistry principles.
- Crowded student benches.
- Limited hood space.

Better

- Need student and instructor buy-in.

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Example 1: Biofuels Labs

- 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

Week 2

Biodiesel Synthesis:
•Balancing reactions
•Density
•Separations

Week 3

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

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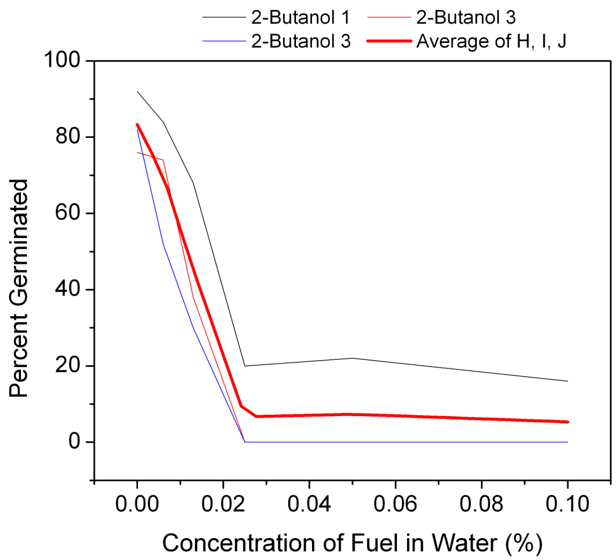
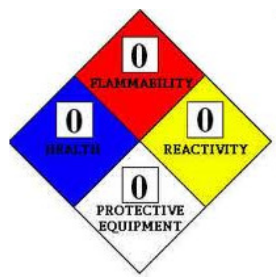
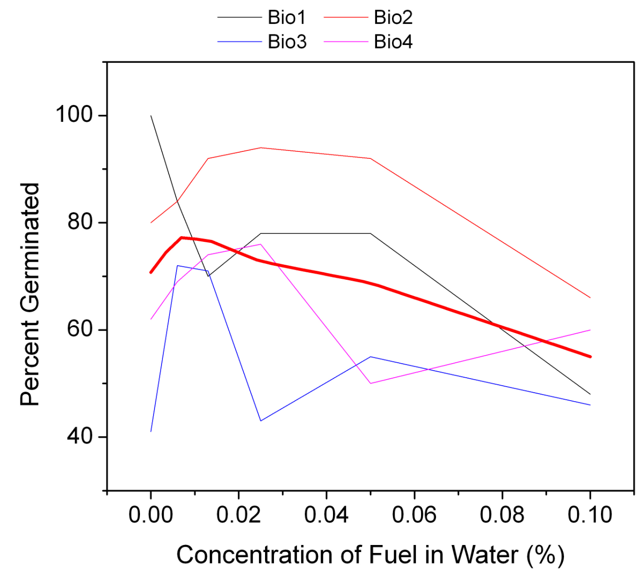
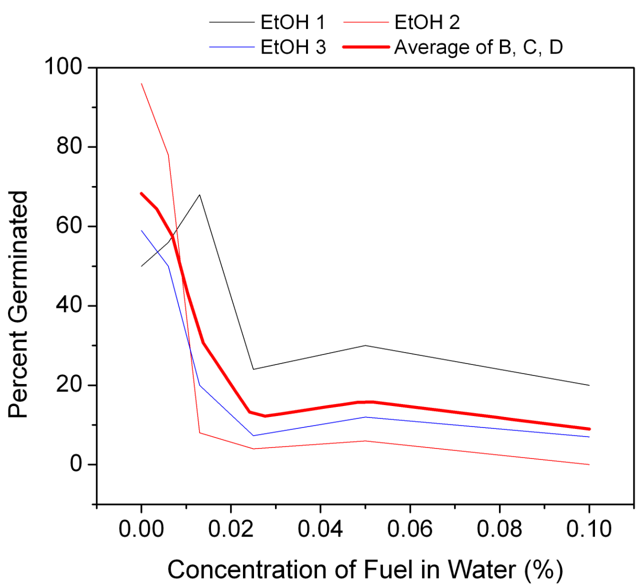
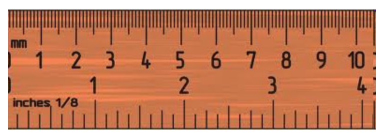
Results from Biodiesel

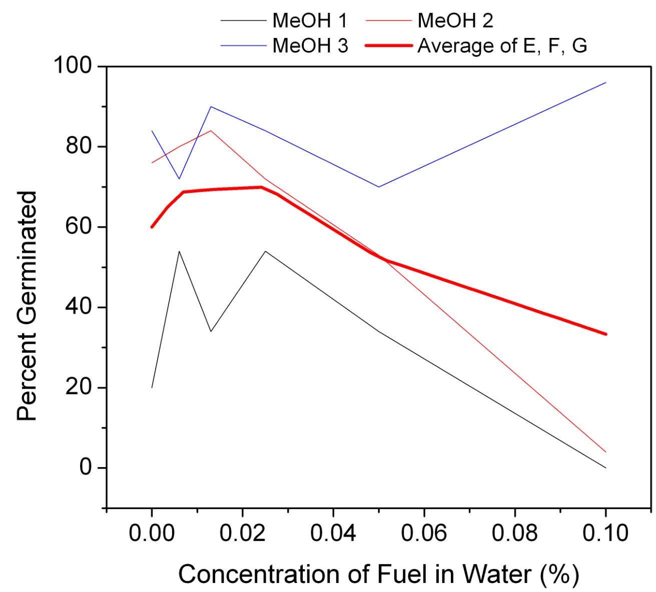












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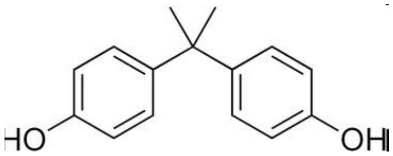
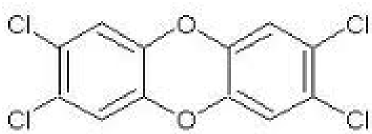
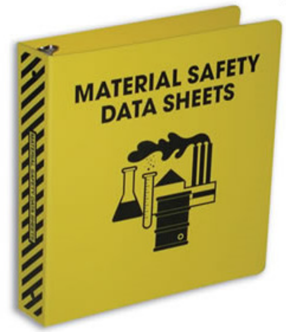
Introducing Chemical Hazards to Chem 1a Students

Chemicals





Resources



Questions

1. Which of the three chemicals would you consider most hazardous? Why?

2. What precautions should you take, if you were using each of these chemicals? Which resource gave you this safety information?

3. Is there safety information that is missing from these resources that you would like to have before working with these chemicals? Is so, what information would you like?

4. Which sources of information are you most likely to use in the future? Why?

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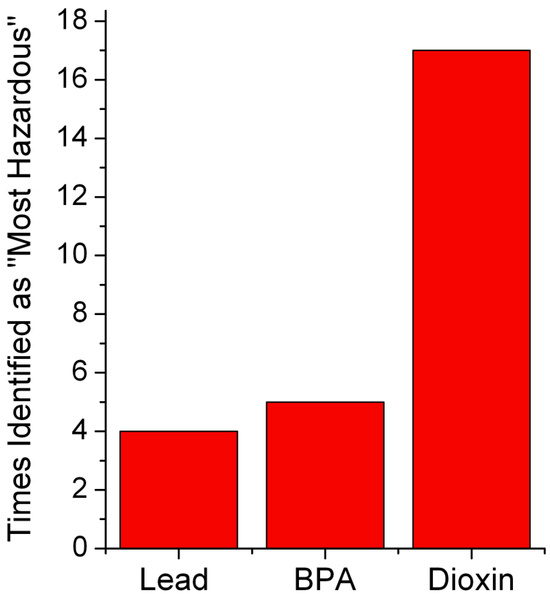
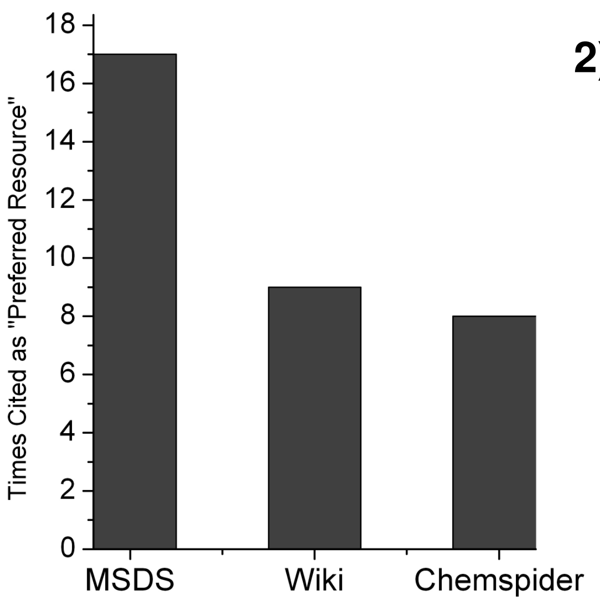
Introducing Chemical Hazards: Student Responces





1) **Students Explored the concept of Hazardous vs. Toxic.**

   "Not only does it [dioxin] have the lowest LD_{50}, but it is the only chemical given that is fatal upon contact with the skin and upon ingestion."

   "I believe BPA is more dangerous because of the high exposure level of BPA to human. BPA is a pervasive compound in our society."

   "Depending on the definition of 'hazardous,' it could easily be all three chemicals. … In conclusion, all three of these chemicals are equally hazardous in different points of view."

2) **Students identify lack of exposure and environmental data**.

   "There is not enough information about the environmental effects of these toxins. I would also like to know where in the house or average city we are most likely to find these toxins."

   "I would like to know how much exposure to these chemical causes sever damage."

   "I wish they talked more about how to be careful during all aspects of our lives…"

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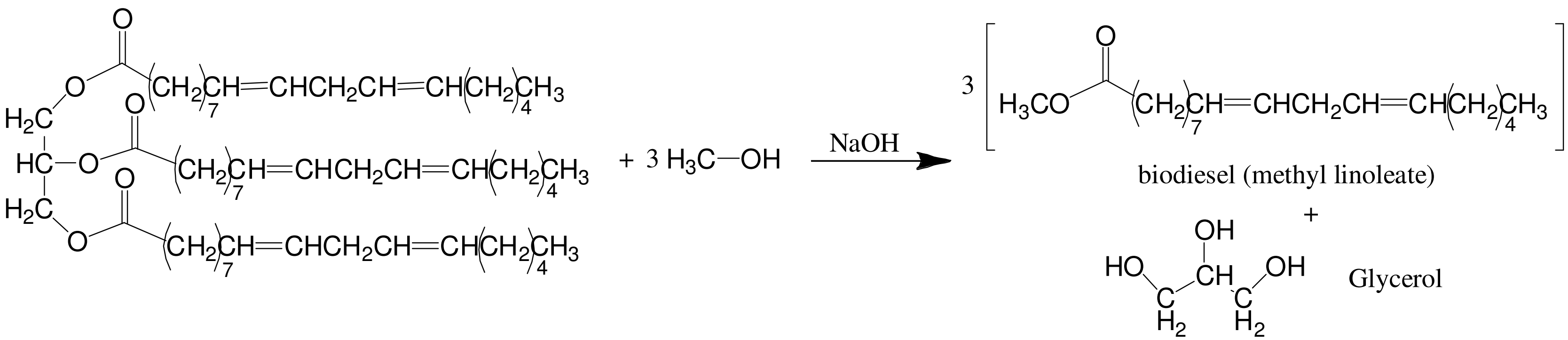
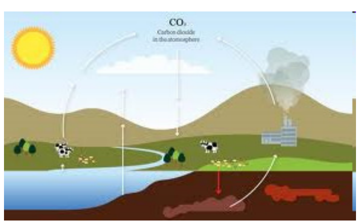
Results from Biodiesel

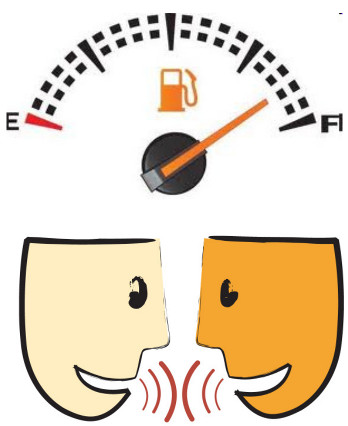
Synthesis of Biodiesel:



Combustion of Biodiesel:

- Using soda can calorimeters.
- About 40% of heat lost to surroundings.
- Use Ethanol as a standard to calibrate.





Student quotes:

"[Biodiesel] has a higher viscosity than gasoline which causes problems when used in cold weather as it would gel up and prevent the car from starting."

"The environmental cost of gasoline is $.71 as compared to $1.45 for corn-based ethanol."

"Biodiesel derived from agricultural grains is susceptible to the same shortfalls as ethanol."

"Biodiesel burns about twice as slow as ethanol…For this reason, large, heavy vehicles that don't need to accelerate quickly use diesel instead of quicker-burning but less efficient fuels."

"Being 'green', we aren't just interested in if we can make fuels that perform similarly to unrenewable resources, but also the effect on the environment."

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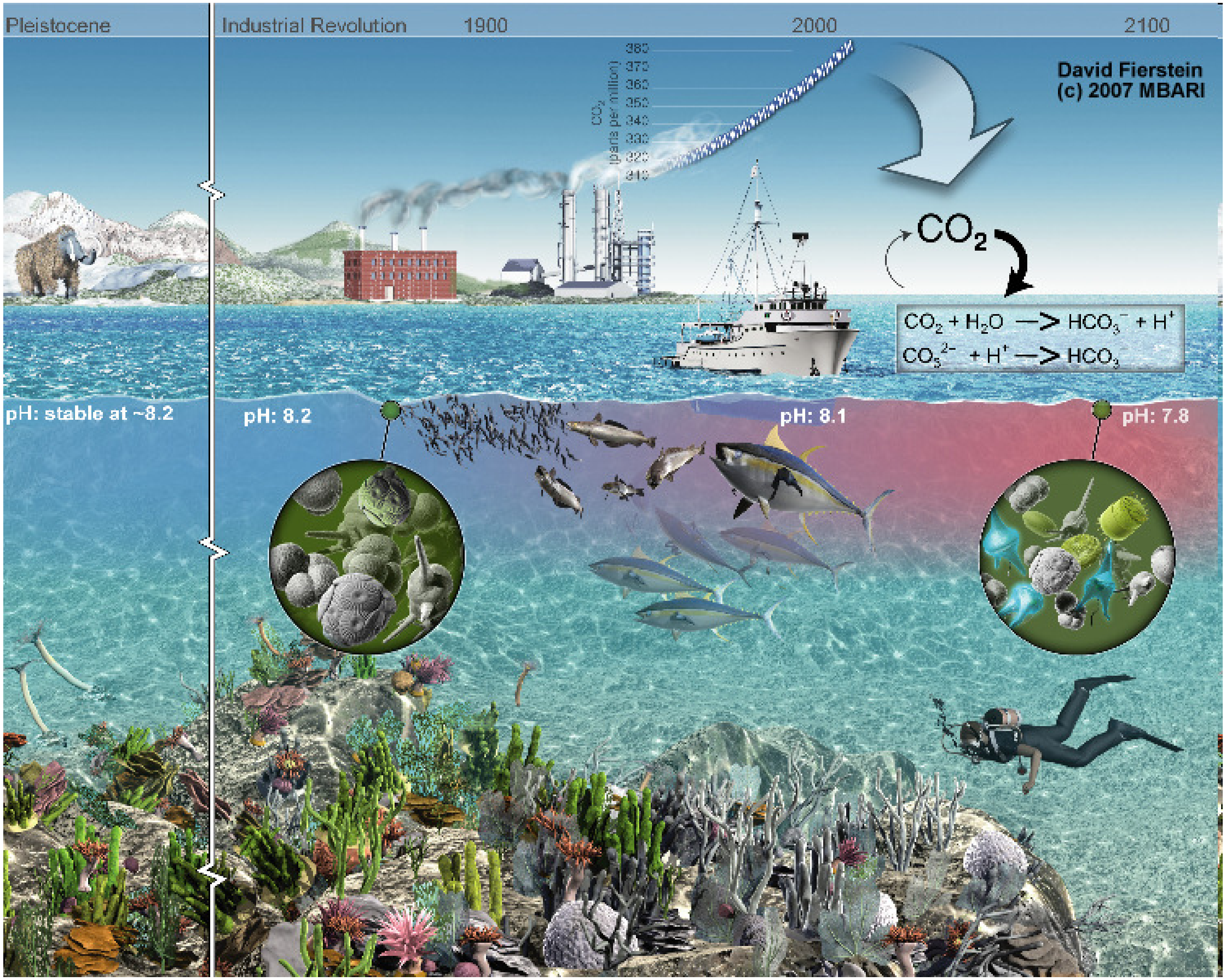
Acids in the Environment



Monterey Bay Aquarium, 2010, http://www.mbari.org/highCO2/

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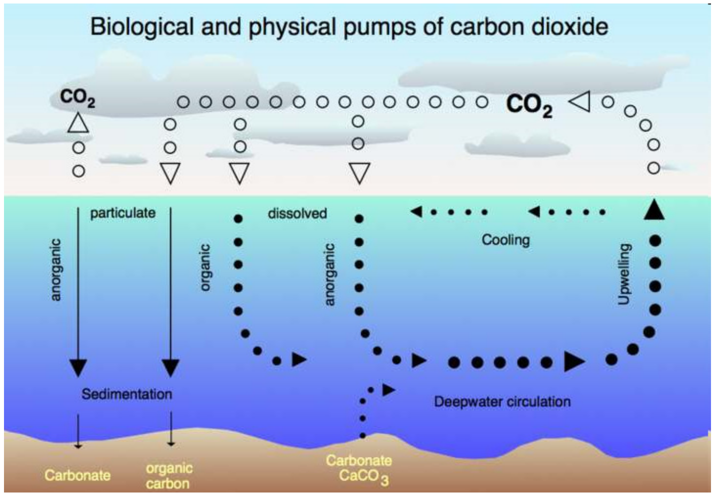
Acids in the Environment



CO_2 Partitioning

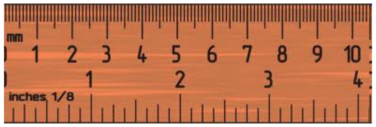
•New lab adapted with permission from ***Microscale Gas Chemistry***, Educational Innovations, copyright Bruce Mattson, 2003Visualize partitioning
•Introduce buffering
•Qualitative kinetics

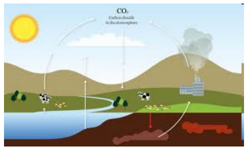
Indicator Titration: Determination of Acid Concentration

•Replaced an indicator titration of HCl with TRIS.
•We tried this lab as an indicator titration of HCl with Na_2CO_3.
•Now it is a titration of an unknown acid solution (HCl) with NaOH.

Potentiometric Titration: Determination of Acid Identity

•Replaced a potentiometric titration of hydrochloric, acetic, formic, and maleic Acids.
•Now the lab uses: HNO_3, H_2SO_4, H_2SO_3, and Na_2CO_3





Student Quotes from Paper

"The degree to which a gas can dissolve into water is expressed by an equilibrium constant…"

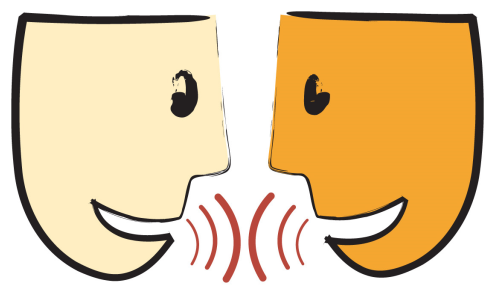
"The truth is that Global Warming and ocean acidification are really one in the same. They are two faces of the same problem."

"As temperatures rise, the solubility of CO_2 in water decreases. But the drop in pH increases the solublity of CO_2 in water…"

Acids in the Environment Final Assignment

In a 1-2 page paper, explain the causes and impacts of ecosystem acidification. Discuss one of the major chemical contributors to acidification (CO_2, SO_x, or NO_x). Be sure to mention the following chemical properties, and how they relate to the transport and effect of your chemical in the environment.

1. Partial Pressure
2. Solubility
3. Ka
4. Concentration
5. Equilibrium



Be as quantitative as possible, using data from reliable sources.

Some potential sources:

1) Scott C. Doney, et al, "The Growing Human Footprint on Coastal and Open-Ocean Biogeochemistry," *Science,* **2010**, 1512, DOI:10.1126/science.1185198.
2) Philip L. Mundaya, et al, "Replenishment of Fish Populations is Threatened by Ocean Acidification," *Proceedings of the National Academe of Science*, **2010**, DOI: 10.1073/pnas.1004519107
3) Michael Tennesen, "Sour Showers: Acid Rain Returns—This Time it is Caused by Nitrogen Emissions" *Scientific American,* **June 21, 2010**, WEB: http://www.scientificamerican.com/article.cfm?id=acid-rain-caused-by-nitrogen-emissions
4) Gabriel Nelson, "Coal Plants Emitting less SO2, NOx this Year, EPA Says," *The New York Times,* **August 17, 2010**, WEB: http://www.nytimes.com/gwire/2010/08/17/17greenwire-coal-plants-emitting-less-so2-nox-this-year-ep-17893.html

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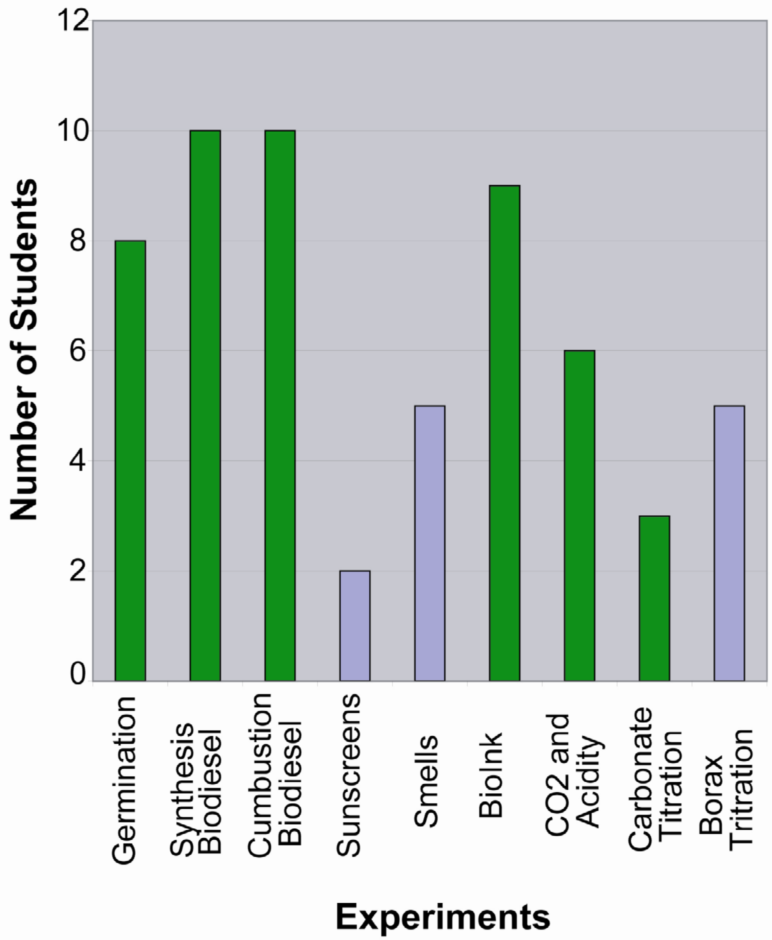
Quantifying initial impacts of Chem 1a Redesign



I think chemistry is a lot cooler now that I can see how it can be applied to current issues!

This lab helped me understand some of the chemical rationales for the green movement.

I have been able to connect chemistry to other sciences like biology better.

It was great to see chemistry at work- it takes the focus off the books and onto tangible actions.

Chemistry is significant to every aspect of our lives, especially to how the environment is changing and being affected by the way we are living.

Chemistry is more useful than I first thought. It gives me hope that green/organic alternatives aren't too unrealistic.

(The labs)made me see how it (Chemistry) is practical and relevant to everyday issues

Before this, I didn't really care for chemistry but it showed life is full of chemistry and the health of the planet depends on our understanding.

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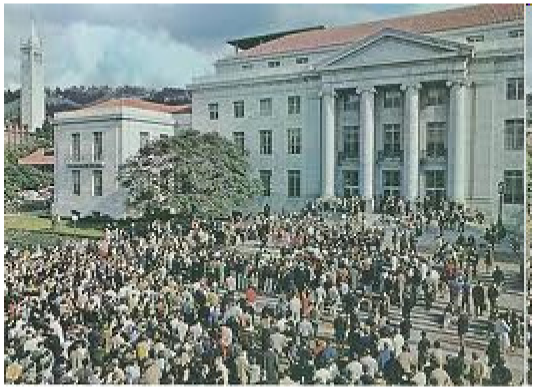
Green Chemistry Education Sandwich

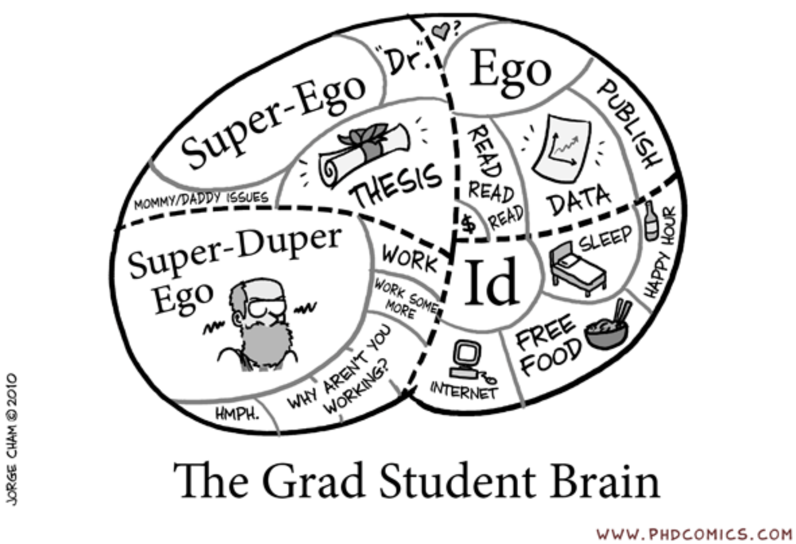


Undergraduate Education

Chem 1a Lab

College of Chemistry
UNIVERSITY OF CALIFORNIA, BERKELEY

Increasing awareness of Green Chemistry at UC Berkeley.



The Grad Student Brain

Graduate Education

1. **Green Chemistry and Sustainable Design Seminar.**
2. **Graduate Class in Green Chemistry.**

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Graduate Student Initiatives

Green Chemistry and Sustainable Design Seminar

Speakers 2010:

Scott Mabury, University of Toronto

Vicki Colvin, Rice University

Berkeley Cue, Pharma Roundtable

Steve Wittenberger, Abbott

Tyrone Hayes, UC Berkeley

Philip Jessop, Queen's University

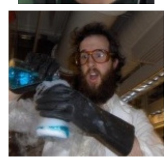
Greg Hughes, Merck

Chi-Huey Wong, The Scripps Research Instituite

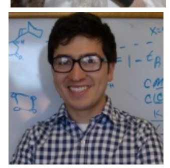
greenchemblog

Don't believe the hype – Understand the science

Learning from past mistakes – Dioxins



Hydrogen-Mediated C-C Coupling to form Allylic Alcohols



Presidential Green Chemistry Awards: Codexis/Merck part 2

From Biomass to Commodity Chemicals

Do water fleas like the taste of nanoparticles?

Dioxygen Activation at Low-Valent Silicon

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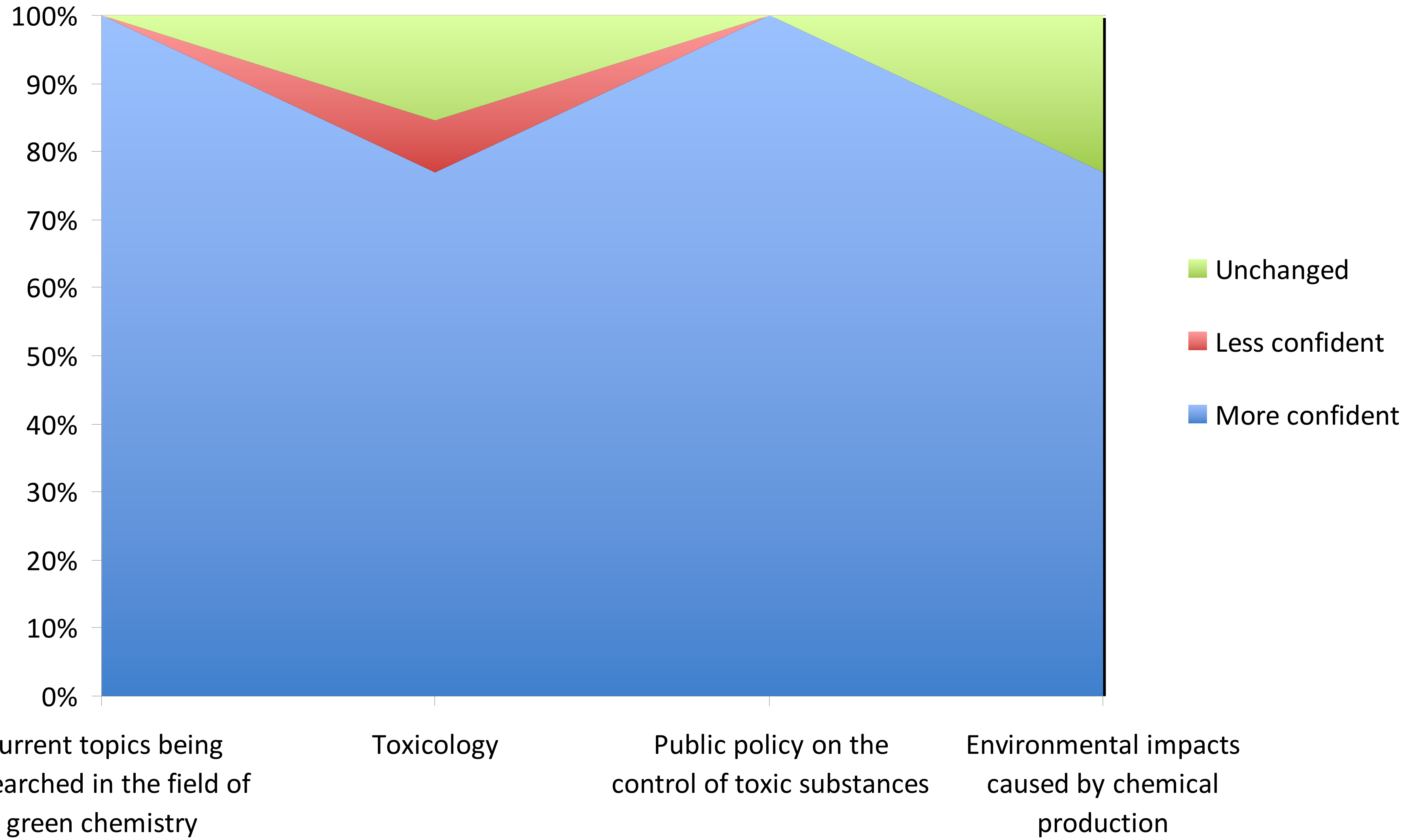
Quantifying Seminar Impact 2008

Percentage of Respondents that Indicated a Change in Confidence in Respontent's Knowledge of the Following Topics After Completing the Seminar



With Neil Tomson

Quantifying Seminar Impact 2008

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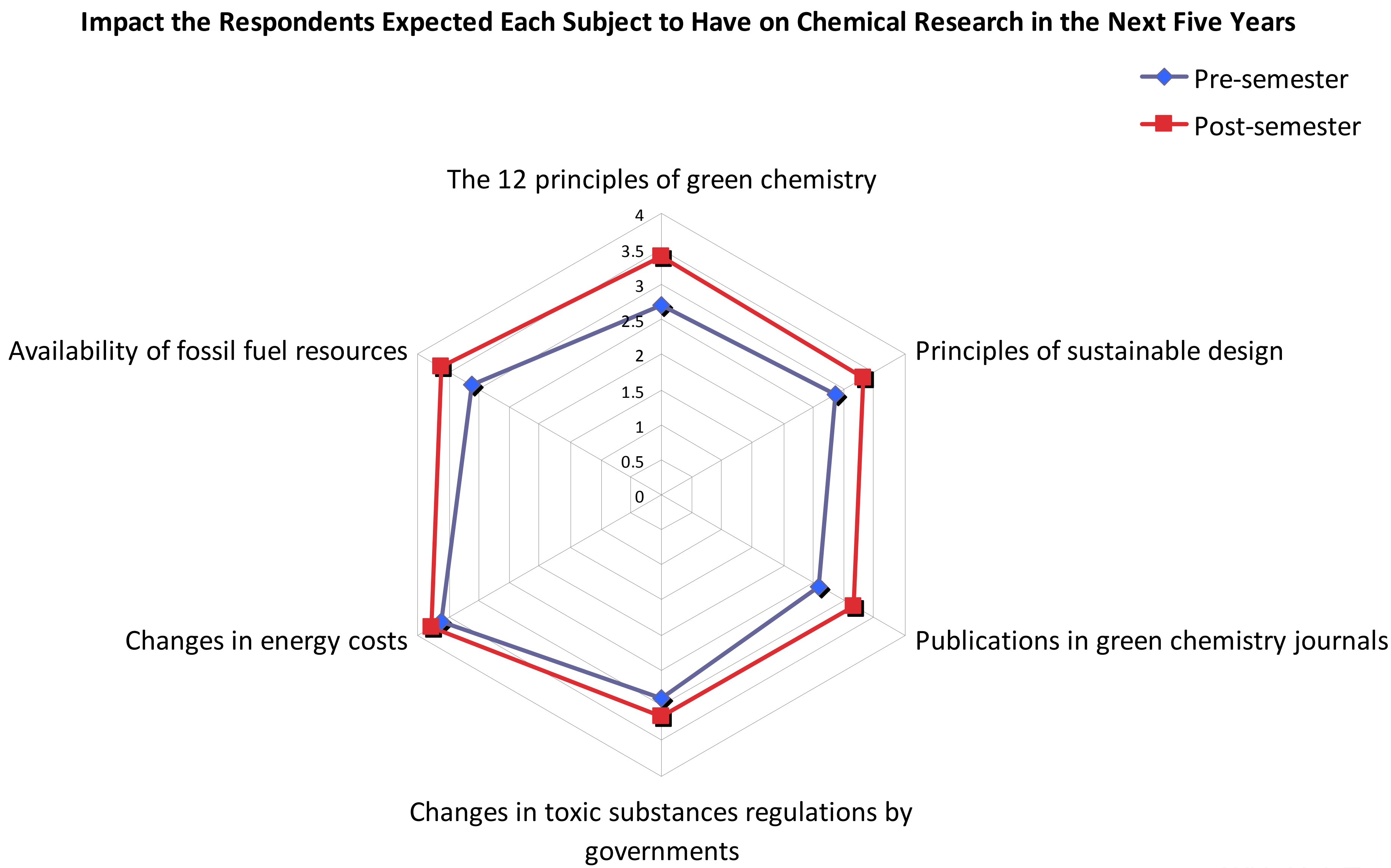
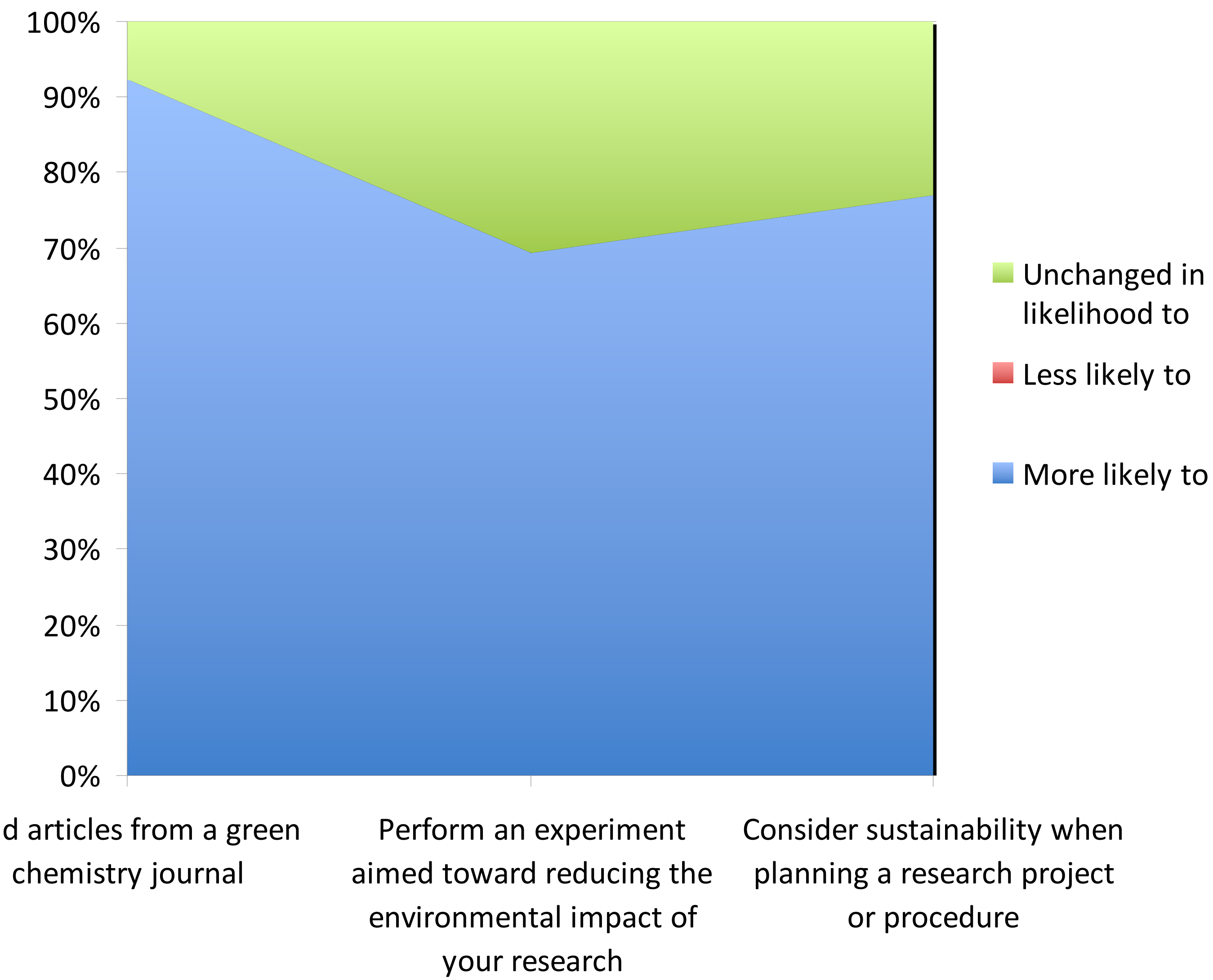


With Neil Tomson

Quantifying Seminar Impact 2008

Percentage of Respondents Indicating a Change in Likelihood to Perform the Following Tasks After Completing the Seminar



With Neil Tomson

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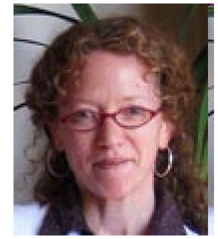
Thanks!

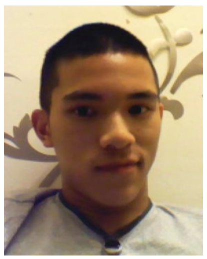

Michelle Douskey


John Arnold


Mike Wilson


Meg Schwarzman

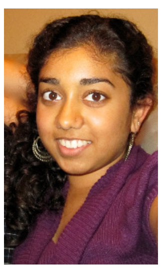
Students


Michael Poon


Casey Finnerty

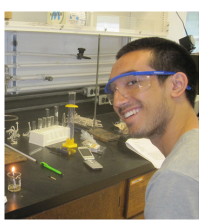

Masaki Yamada


Milton Mi


Swetha Akella


Jeff Jelsma


Amanda Polley


Max Babicz


John Holbrook

Department of Chemistry

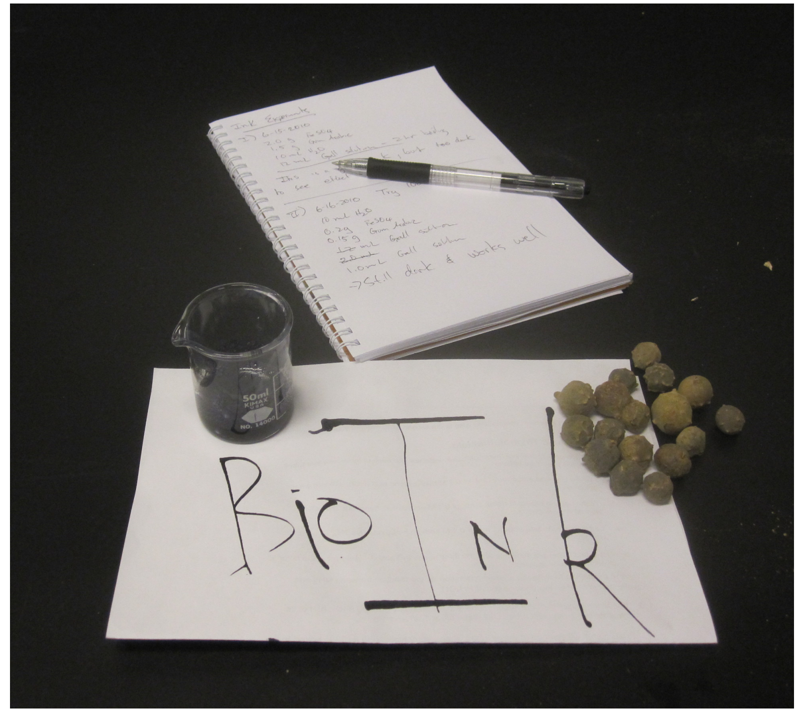
Chunmei Li
Bob Lamoureux
Angy Stacy
Rich Mathies
All of my students this summer!

Funding

- Cal EPA: DTSC
- Dow Foundation: Sustainable Products and Solutions Program
- Department Chemistry 1a Stock Room

"I'm into Green Chemistry because I don't want my kids to have to live off-world." –Casey Finnerty, 2010

BioInk-Part of the Equilibrium Inquiry



Original lab included:

1. Solubility equilibrium of Chromium salts.
2. Acid/Base indicator equilibrium.

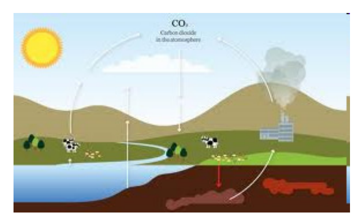
New lab includes.

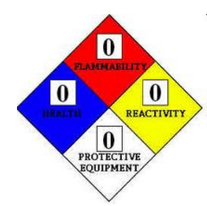
1. $CuSO_4$ solubility equilibrium.
2. Acid/Base indicator equilibrium.
3. BioInk redox reaction.

Student Quotes from end of semester reflection:

"Green chemistry does not always require new methods i.e. the bioink lab. We can learn this from the past."

"Chemistry is more useful than I first thought. It also gives me hope that green/organic alternatives aren't too unrealistic."





Continued 1a Development

Nutrition Action Healthletter, Oct, 2008, p 10.

Proposed Labs

1. Extraction of natural dyes from turmeric and beets.
2. Chromatography to identify unknown dyes in products.