Engineering Practices in High School Chemistry

NGSS Science and Engineering Practices for Chemistry Teachers

Steve Sogo, Laguna Beach High School
Bruce Wellman, NBCT, Engineering Academy, Olathe Northwest HS
Introduction of speakers:

Steve Sogo
• Chemistry teacher for 27 years in CA
• 2017 PASCO STEM Educator Award
• 2013 Frey Scientific Award for Inquiry-based Science Teaching
• Lead author for AACT’s Chemistry of Cars lessons

Bruce Wellman
• Chemistry teacher for 15+ years in DE, CA, & KS
• National Board Certified Teacher, AYA Science (Chemistry)
• 2009 PAEMST, KS Science
• 2011-12 Classroom Teacher Ambassador Fellow, US Department of Education
• ASEE BOD Committee on P-12 Engineering Education
Why Include Engineering in HS Chemistry?

- Real-world problem-solving is motivating for students!
- Application of scientific concepts leads to a deeper understanding & greater retention.
- Builds teamwork skills.
Differences between design in Science vs. Engineering

- **Science Experimental design** - trying to determine the relationships among different variables related to a physical phenomenon. (Why do things work this way?)
- **Engineering design** - developing an optimal solution to a defined problem by manipulating given variables to produce a desired outcome. (What can be done with this scientific knowledge?)
- **Tinkering** - (Maker Movement)
Resource to help frame parts of Engineering Design: The Informed Design Teaching and Learning Matrix

<table>
<thead>
<tr>
<th>DESIGN STRATEGIES</th>
<th>BEGINNING vs. INFORMED DESIGNER PATTERNS</th>
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<tbody>
<tr>
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<td>WHAT BEGINNING DESIGNERS DO</td>
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<td>Understand the Challenge</td>
<td><strong>Pattern A. Problem Solving vs. Problem Framing</strong></td>
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<td>Treat design task as a well-defined, straightforward problem that they prematurely attempt to solve.</td>
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<td>Delay making design decisions in order to explore, comprehend and frame the problem better.</td>
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<td>Skip doing research and instead pose or build solutions immediately.</td>
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<td>Do investigations and research to learn about the problem, how the system works, relevant cases, and prior solutions.</td>
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<td>Generate Ideas</td>
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<td>Work with few or just one idea, which they can get fixated or stuck on, and may not want to change or discard.</td>
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<td>Practice idea fluency in order to work with lots of ideas by doing divergent thinking, brainstorming, etc.</td>
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What does engineering look like in HS Chemistry

• Varying time commitment: from 20-minute activities to week- or month-long projects
Lesson Plan: How far can we go?

FOR THE TEACHER

Summary
In this lesson students compare energy densities of lead acid and lithium ion batteries to understand the relationship between electrochemical cell potentials and utilization of stored chemical energy. Students will calculate the mass and volume of a battery pack capable of propelling a car for 100 miles.

NGSS Standards
- HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
- HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
Assignment #171: Let There Be Light!
Building batteries in the lab

In the beginning, God created the heavens and the earth, and the earth was without form and void. ... And God said, “Let there be light.” And there was light. Genesis 1:1-1:3

Overview: Your goal in this lab is to make a powerful battery, capable of lighting up some miniature light bulbs (LED’s). You will all start by making a standard copper/zinc cell. Then you will try to make a better battery using a particular “special ingredient”.

Part One: For the zinc/copper cell, you should use:
1. Two 250 mL beakers, each containing 75 mL of distilled water
2. A strip of zinc metal (for use as an electrode)
3. A strip of copper metal (for use as an electrode)
4. Between 1.2 and 1.6 grams of solid copper sulfate
5. Between 1.2 and 1.6 grams of solid zinc sulfate
6. A salt bridge (filled with .25 M Na₂SO₄).
Students develop antivenom in high school lab

20 June 2013 Jennifer Newton

A US high school teacher and nine of his students have made nanoparticles that can neutralise venom from one of the most dangerous snakes in Africa. These nanoparticles could offer a way to make cheaper and more practical antivenoms.

Traditional antivenoms are made by injecting sublethal toxin doses into an animal to invoke an immune response. Antibodies produced in this immune response are then harvested from the animal’s serum. Such antivenoms are not only expensive but also required refrigeration – a major limitation considering antivenoms are often required in remote locations.

Now, Steven Sogo and his best students from Laguna Beach High School in California, have synthesised nanoparticles that will selectively bind to toxins in venom from the Mozambique Spitting Cobra. In vitro tests showed that, by binding to the toxins, the nanoparticles can prevent the toxins from causing cellular damage.
Incorporating Engineering into a 90-minute Chemistry Lab

The *Less than Zero* Lab:

Goal = utilize an endothermic reaction (baking soda + HCl) to chill a solution to below zero degrees Celsius.

Format: A scripted reaction followed by guided experimental design leading to an optimized system.

Optional: Run as a contest—who can get the lowest temperature??
The Initial Scripted Reaction

Part I (scripted reaction):

1. Weigh out between **2.80** and **3.20 grams** of baking soda (NaHCO$_3$) on weighing paper.

2. Use a **graduated cylinder** to measure **25 mL of 2 M HCl** into a 250 mL beaker. Measure the initial temperature of the acid.

3. While the thermometer is running (recording data on the computer screen), carefully add the pre-weighed **baking soda** to the beaker. Stir gently with the thermometer and record data until the reaction is complete.
Analysis of the reaction

The reaction that occurs in the beaker is:

\[ \text{NaHCO}_3 (s) + \text{HCl (aq)} \rightarrow \text{NaCl (aq)} + \text{H}_2\text{O (l)} + \text{CO}_2 (g) \quad \Delta H = +28 \text{ kJ/mol} \]

a) Use the \( \Delta H \) value for the reaction given above to calculate the number of joules absorbed when reacting the mass of baking soda (\( \text{NaHCO}_3 \)) you weighed out in step #5.

b) Convert the joules in (a) to calories.

c) Divide your calories from (b) by the number of grams of solution you have in your beaker. This will give you a theoretical value for how much your temperature should have dropped during the reaction.

d) Compare your theoretical temperature drop from (c) to the actual experimental temperature drop you recorded with the thermometer. Ponder why these numbers are not the same.
Engineering the system for optimal effects

Your goal is to improve the system to achieve a temperature BELOW ZERO DEGREES Celsius. The questions shown on the next page are designed to have you consider possible avenues for modification. These are NOT the only things that you could change. The best strategy will be to carefully discuss the parameters you would like to change (and why) prior to performing actual experiments. You are allowed only two experimental trials.
Guiding questions to define the problems to be solved

- Does the container affect the results of the experiment? *Ceramic, metal and Styrofoam vessels are available.*
- Is the ratio of baking soda to acid that you used in the first reaction the "right" ratio?
- Would there be an advantage to adding some **extra water** to the reaction?
- Is there an advantage to scaling up or scaling down the reaction? *You may want to use more moles or fewer moles in your reaction mixture*
- Is the volume of acid important? If so, do you want more or less volume in your reaction?
- Would there be an advantage to using a different molarity of acid? *1 M, 2 M, 3 M, and 6 M HCl are available*
Extra mass is detrimental

Need to calculate a 1:1 mole ratio

I've calculated something that might be crazy, but it might work... 

I deserve Ice Cream!

We could win this!!!!!
Vary levels of complexity & Target Temperatures

• Provide scaffolding for individuals or entire class
• Change supplies to increase the challenge or reduce the challenge level
• Vary target temperatures per class hour or per year to insure new techniques are required
Reflection upon Engineering Practices

• Provide way for students to reflect on their engineering skills
• Provide metacognitive tool for providing students a way to think about how they are designing their engineering designs
• In practical use, only focus on one or two aspects of the design process (otherwise will overwhelm students)
Reflection upon Engineering Practices

The Informed Design Teaching and Learning Matrix

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<td>Represent Ideas</td>
<td>Pattern D. Surface vs. Deep Drawing &amp; Modeling</td>
<td>Propose superficial ideas that do not support deep inquiry of a system, and that would not work if built.</td>
</tr>
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<td>Weigh Options &amp; Make Decisions</td>
<td>Pattern E. Ignore vs. Balance Benefits &amp; Tradeoffs</td>
<td>Make design decisions without weighing all options, or attend only to pros of favored ideas, and cons of lesser approaches.</td>
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Questions up to this point?

- Engineering design cycle?
- Design learning matrix?
- Adapting a lab to include engineering?
1 week and longer projects: Benefits and Challenges

Rocket Project

Stoichiometric calculations

Activation energies

Gas Laws

Thermodynamics
An Example Long Term Project
Water Filtration Design Challenge: Design it Clean

Much of the world does not have access to clean drinking water. The impact on human health as a result of this shortage of clean water has the greatest effect on the most vulnerable segments of societies: children, the elderly, and ill persons. In this design challenge you will design a filtration system that is effective at removing sediment particles and ammonia from a water source and is based upon real physical and cultural conditions found in a specific location in the world.

Main Learning and Design Objectives:
1. Design a filtration process which reduces the turbidity of a water sample.
2. Design a filtration process which removes ammonia from a water sample.
3. Design a filtration process which is viable in a specific geographic and cultural setting.

1 Based upon the Design It Clean project based learning by The New York Hall of Science, take from: http://pblu.org/projects/design-it-clean (accessed on 29 September 2014)
Students working and work samples
An Example Long Term Project: Water Filtration

• Human Centered Design

• Connected to the National Academy of Engineering’s Grand Challenges

• Connections - local water company

Link to Wellman’s Resources: https://goo.gl/aawPH1

2 http://www.engineeringchallenges.org/
Lesson Plan: Mechanisms and Properties of Airbags

FOR THE TEACHER

Summary
In this lesson students will learn about the mechanisms and properties of airbags, and examine the choice of airbag inflator from several points of view.

Grade Level
9-12 High School

NGSS Standards

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) (secondary to HS-PS2-3) (secondary to HS-PS3-3)
- When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental impacts. (secondary to HS-LS2-7) (secondary to HS-LS4-6) (secondary to HS-ESS3-2),(secondary HS-ESS3-4) (HS-ETS1-3)
Webquest Engineering: Airbag Chemistry

Background
Airbags protect drivers and passengers in automobiles by providing a pillow of gas between them and a car frame, dashboard or windshield. You are going to research the chemistry and technology of an airbag, and explain this to others using an infographic. An infographic allows data to be sorted, arranged and presented visually. (Annie Colbert, [http://mashable.com/2012/07/18/lego-infographic/#xy2kvSN_vqqB](http://mashable.com/2012/07/18/lego-infographic/#xy2kvSN_vqqB))

Objective
To produce an infographic which depicts airbag chemistry and technology.

Procedure
Part I: Research
1. Research the chemistry and technology of airbags. You should answer the questions below:
   - What are the parts of an airbag?
   - What gas is produced in an airbag deployment?
   - How is the gas produced?
   - What are the specific chemical reactions that produce the gas?
   - Can you describe the thermodynamics of the chemical reactions? For example, are they exothermic or endothermic?
   - How does an airbag protect an automobile occupant?

In addition, you should solve the following problem using stoichiometry and the ideal gas law. Incorporate the answer in your infographic:

A standard air bag has a volume of 65 L. Assuming that the pressure = 1.00 atm and the temperature is 25 degrees C, what mass of sodium azide is needed for the reaction? In your calculation, you can assume that the first reaction (the decomposition of sodium azide) is the primary reaction for the production of nitrogen.
Lesson Plan: The Right Polymer for the Job

FOR THE TEACHER

Summary
In this lesson students are introduced to polymeric materials by exploring polymers (mostly plastics) used in automobiles. Students will learn features that all polymeric materials have in common and features that distinguish one polymer from another on the molecular level. Students will learn how the molecular differences translate into property differences. The selection of a polymer with the right properties for any particular application is critical to the ability to meet the requirements of that application.

Grade Level
High School

NGSS Standards
- HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- ETS1.B: Developing Possible Solutions
  - When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)
Webquest Engineering: Polymers/Plastics in Cars

Results/Data/Observations

Table 1. List of Plastics Used in Automobiles

<table>
<thead>
<tr>
<th>Plastic item</th>
<th>Where found in car</th>
<th>Purpose/function</th>
<th>Type of plastic</th>
</tr>
</thead>
</table>

Table 2. Performance Requirements for Selected Plastic Part

<table>
<thead>
<tr>
<th>Plastic item</th>
<th>Temperature stability</th>
<th>Chemical resistance</th>
<th>Color/clarity</th>
<th>Texture</th>
<th>Flexibility/rigidity</th>
<th>Strength</th>
<th>...</th>
</tr>
</thead>
</table>

Analysis

Answer the following questions.

1. How many plastic items were you able to list in Table 1?
2. How many different plastics were used to make these items?
3. From your prelab work, what do all plastics have in common at the molecular level?
4. What features of the plastic you studied make it the "right plastic for the job"?
Lesson Plan: How Fuel Cells Work!

FOR THE TEACHER

Summary
In this lesson students will investigate how fuel cells provide energy in modern cars.

Grade Level
High School

NGSS Standards
- HS-ETS1-3: Evaluate a solution to a complex real-world problem based on priorities criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
- HS-PS1-2: Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- PS1.B: Chemical Reactions. The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict reactions.
Fuel Cell Engineering: Web + Hands-on

Teacher Notes

- **Engage:** I will do this activity in the electrochemistry unit after watching and discussing “Pump” (a film on the history of the internal combustion engine) and the challenges of reducing CO₂ emissions. The film can be streamed on Netflix. I think this frames the activity in a way that has kids naturally ready to hear about alternative fuel vehicles and the challenges of global climate change. You should find your own natural way to get students engaged.

- **Explore:** The activity starts with a review of the basics of oxidation and reduction reactions (simulation) and takes them through an exploration of how fuel cells work on a chemical level, and then into an exploration of the advantages and disadvantages of fuel cell vehicles.

- **Explain:** Students could present their findings to each other about how fuel cells work or the pros/cons of fuel cell vehicles, or the teacher could lead a discussion. It might also be helpful to discuss how fuel cells are similar/different from voltaic cells (batteries).

- **Elaborate:** Teacher could extend/elaborate on this topic by discussing other applications of fuel cells, such as ethanol or methanol fuel cell vehicles, or ethanol fuel cells used in alcohol detection devices (breathalyzers or Continuous Alcohol Monitoring bracelets) used to deter drunk driving offenders. The fuel cells in these devices work in a very similar fashion but use methanol or ethanol as the fuel. If budget and time permit, it would be great if students could build and operate a fuel cell model car. Kits are available starting at less than $100 and The Fuel Cell Store provides worksheets and lesson plans as well for teacher and student. They’re really good and can be approached from RedOx or Energy Conservation and Transformation context. They even include NGSS standards in the teacher guides. Follow the link below for the kit and lesson plans/activities.
Webquest Engineering: The power of argument

https://youtu.be/yFPnT-DCBVs
Resources for engineering design projects


• Sogo Labs/Projects (Rocket Lab, Alien Blood, Keep ‘em Separated, Radiator design): [https://lbusd.haikulearning.com/ssogo/resourcesforchemistryteachers](https://lbusd.haikulearning.com/ssogo/resourcesforchemistryteachers)

• Link to Wellman’s Resources: [https://goo.gl/aawPH1](https://goo.gl/aawPH1)

• ChemEd/BCCE resources: Bernstein, Price, Bracken

• Other Engineering Education resources
  
  o teachengineering.org
  
  o NAE - website - [http://linkengineering.org/](http://linkengineering.org/)
  
Resources for professional development

The resources listed are to assist K-12 teachers who wish to become teachers of engineering.

The first document below provides a comprehensive description of the professional preparation and development required to fully prepare teachers of engineering. The second document is a matrix for evaluating a given program for teacher preparation or professional development.

- Standards for Preparation and Professional Development for Teachers of Engineering
- K-12 Teachers of Engineering - Professional Development Matrix
- An Introduction to the Standards for Professional Development for Teachers of Engineering

Taken from:  https://goo.gl/qr3oCa , links to the PDF versions of these documents can be found there.
Questions?
Survey, Certificate, and Downloads

To complete a brief survey about this webinar, and to generate your certificate of attendance, visit: http://bit.ly/aactpd

To Download Resources: http://bit.ly/EngPractice