Designing Green Chemistry Labs for High and Middle School

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My School

Tuition-based K-12
IB continuum
Prov. curriculum
Our 15 min. Goal

To introduce you to learning activities through which

• HS/MS chemistry students learn the first three Green Chemistry Principles

• HS/MS chemistry students utilize the first three Green Chemistry Principles in the critical analysis of experimental success
Green Chemistry Principles

1. It is better to prevent waste than to treat or clean up waste after it is formed • **Prevention**

2. Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product • **Atom Economy**

3. Wherever practicable, synthetic methodologies should be designed to use and generate substances that pose little or no toxicity to human health and the environment • **Less Hazardous Chemical Synthesis**

Gravimetric Stoichiometry

\[
\text{Sr(NO}_3\text{)}_2(\text{aq}) + \text{CuSO}_4(\text{aq}) \rightarrow \text{SrSO}_4(\text{s}) + \text{Cu(NO}_3\text{)}_2(\text{aq})
\]

\[K_{sp} = 3.1 \times 10^{-7}\]

Double replacement reactions are pedagogically important, providing HS students with practical applications of mass-mole and stoichiometric relationships.
Activity Part 1: Overview

“Propose two aqueous reactants that will react to form a precipitate”

• 34 Gr. 11 students in groups of 2-4 (22 gave informed consent)
• Design, implement, and evaluate a precipitation experiment
• Define success criteria for the experiment and procedure
• Summarize how the GHS symbols, the NFPA symbols, and SDS relate to one another for each product and reactant
• Write a detailed safety protocol that addresses hazards and accounts for proper waste disposal
**NFPA vs GHS**

**NFPA “fire diamond”**

- **fire**
- **health**
- **reactivity**
- **special hazard**

0 – minimal, 4 – severe

**GHS symbols**
Activity Part 1: Student Design

Group of strongest students

\[
\text{CdSO}_4(\text{aq}) + \text{K}_2\text{S}(\text{aq}) \rightarrow \text{CdS}(\text{s}) + \text{K}_2\text{SO}_4(\text{aq})
\]

\[K_{sp} = 1.1 \times 10^{-25}\]
Activity Part 1: Design Summary

- 2 of 16: both reactants NFPA ≤ 2
- 1 of 16: both reactants NFPA ≥ 3
- 13 of 16: one reactant NFPA ≥ 3

- Highly toxic (CdSO₄ and Ba(NO₃)₂) or both (FeCl₂)
- Highly corrosive (NaOH and KOH)
Activity Part 1 : Conclusions

- Students chose these precipitation reactions even though they had been instructed to evaluate the hazards of their experiment.
- Only one group of students chose success criteria resembling experimental yield calculation.
- Solubility tables played the greatest role in these students' choices of reactants.
Process Mass Intensity

\[
PMI = \frac{\text{total mass process}}{\text{mass product}}
\]

PMI can be readily calculated by Grade 11 students and provides better insight into the optimization of resources, according to GCP

Concepcion Jimenez-Gonzalez, Celia S. Ponder, Quirinus B. Broxterman, and Julie B. Manley Organic Process Research & Development 2011 15 (4), 912-917 DOI: 10.1021/op200097d
Activity Part 2: Teacher Design

\[ \text{MgCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{MgCO}_3(\text{s}) + 2\text{NaCl}(\text{aq}) \]

yield 30-40%

\[ K_{sp} = 1.4 \times 10^{-5} \]
Activity Part 2: Student Data

\[ \text{MgCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{MgCO}_3(\text{s}) + 2\text{NaCl}(\text{aq}) \]

<table>
<thead>
<tr>
<th>solute mass (g)</th>
<th>1.210 g</th>
<th>0.540 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>solution vol (mL)</td>
<td>50 mL</td>
<td>50 mL</td>
</tr>
<tr>
<td>precip. mass (g)</td>
<td></td>
<td>0.195 g</td>
</tr>
</tbody>
</table>

\[
\text{PMI} = \frac{\text{total mass process}}{\text{mass product}} = \frac{1.210 + 0.540 + 50 + 50}{0.195} = 520
\]

- results between 468 and 907
- low 106; high 1493
Activity 2: Evidence of Learning

“A higher PMI means more waste was created in order to get the amount of product. When attempting to lower PMI, it is logical to try and reduce the mass of the chemicals. This could be as simple as reducing the amount of water used in the experiment.”

Student
Final Conclusions

• High School students can critically assess the hazards associated with reactants and products to learn and apply GCP 3, through consideration of the NFPA symbols

• High School students can optimize their experimental design with PMI to learn and apply GCP 1 and 2

Thank you for your time and attention

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