Teaching future chemists how create meaningful risk assessment tools
• For a given task or chemical, a job hazard analysis can be used to identify potential hazards, determine the risk posed by those hazards, and establish controls to minimize them to prevent damage or exposure (meets RAMP)

• To create a meaningful assessment tool, information must be focused into some structured order

• Organizing safety information to minimize risk is not an intuitive process for students

• Students can be taught how to assimilate information so as to understand and control the hazards using hazard analysis methodology
Teaching Students to Think About Hazard & Risk

Why Hazard Analysis?
Hazard/Risk Analysis

- Information Assimilation
- Chemical Hygiene
- Written & Oral Communication
Where Does This Fit into Our Curriculum?

- In our Chemical Safety course
- In our Senior Capstone course
- As individual instruction
- In undergraduate research
• Using a hazard analysis tool to teach hazard/risk ties in nicely to the 2015 ACS CPT Guidelines for undergraduate programs by connecting –
  ▫ Chemical Safety Skills
  ▫ Chemical Literature and Information Management Skills
  ▫ Undergraduate Research, and the
  ▫ Capstone Experience
7.2 Chemical Literature and Information Management Skills

- ...the ability to retrieve information efficiently and effectively by searching the chemical literature
- ...evaluate technical articles critically
- ...manage many types of chemical information
- ...be instructed in effective methods for performing and assessing the quality of searches using keywords, authors, abstracts, citations, patents, and structures/substructures.
- The program [accredited] should provide ready access to technical databases with sufficient depth and breadth of the chemical literature for effective searching.
7.3 Laboratory Safety Skills

- carry out responsible disposal techniques
- comply with safety regulations
- properly use personal protective equipment to minimize exposure to hazards
- understand the categories of hazards associated with chemicals (health, physical, and environmental)
- use Safety Data Sheets (SDSs) and other standard printed and online safety reference materials
- recognize chemical and physical hazards in laboratories, assess the risks from these hazards, know how to minimize the risks, and prepare for emergencies
6. Undergraduate Research

• The research project should...promote awareness of advanced safety practices, and be grounded in the primary chemical literature.

• A student using research to meet the ACS-certification requirements must prepare a well-written, comprehensive, and well-documented research report, including safety considerations where appropriate.

5.10 Capstone Experiences

• ...programs to assess the ability of students to integrate knowledge, use the chemical literature, and demonstrate effective communication skills.
Where Do You Get the Information?
Suggested

- Make sure that the SDS used is a GHS version
- Go beyond online encyclopedia sources
- Go to glove manufacturer site if needed

...use Safety Data Sheets (SDSs) and other standard printed and online safety reference materials

Links to Information Sites

The links listed here will connect chemical workers to the most reliable (and in most cases peer reviewed) internet resources so that they may access the necessary information to understand the hazards associated with the chemicals used in their laboratory. This will enable workers to create trustworthy risk assessment tools. These are very powerful databases and sources which are offered for free use on the internet by the indicated agencies. There are also links to sites such as the Acronym Finder and the Wayback Machine which are very useful in interpreting data and retrieving broken links.

<table>
<thead>
<tr>
<th>Site</th>
<th>Agency</th>
<th>Use(s)</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory Biosafety Manual</td>
<td>National Oceanic and Atmospheric Administration (NOAA)</td>
<td>The Computer-Aided Management of Emergency Operations software allows the user to mix chemicals in a virtual scenario to check for reactivity between chemicals and chemical groups. This allows one to check chemical compatibility for storage or waste containers. It is available as a web application, mobile website, or as a downloadable application.</td>
<td><a href="http://www.camochemicals.noaa.gov/you/bringit/">http://www.camochemicals.noaa.gov/you/bringit/</a></td>
</tr>
</tbody>
</table>
The program should provide ready access to technical databases with sufficient depth and breadth of the chemical literature for effective searching.
...be instructed in effective methods for performing and assessing the quality of searches using keywords, authors, abstracts, citations, patents, and structures/substructures.
The Learning Process
Creating a Cognitive Category

- In general, students have not had much experience with chemical hygiene concepts beyond the rules
- A basic lecture is required on risk, hazards, basic toxicology, GHS, and how & where to find reliable information, hierarchy of controls
- Work through sample tasks in class
- Common assignment to produce a JHA
- Reflective learning and assessment
- Create a JHA for their senior research
The Process Logic

- Write a complete task statement
- List the equipment & chemicals required
- Break the task into an appropriate number of steps
- Determine the hazard(s) for each step
- Assign risk for each step
- Put the correct controls in place to reduce or eliminate the risk
## Similarities to Scientific Writing

A Communication Skill

<table>
<thead>
<tr>
<th>Job Hazard Analysis</th>
<th>Research Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Writing a complete task statement</td>
<td>Statement of purpose/Introduction</td>
</tr>
<tr>
<td>• Listing the equipment &amp; chemicals required</td>
<td>Experimental/Methods &amp; Materials</td>
</tr>
<tr>
<td>• Breaking the task into an appropriate number of steps</td>
<td></td>
</tr>
<tr>
<td>• Determining the hazard(s) for each step</td>
<td></td>
</tr>
<tr>
<td>• Assigning risk for each step</td>
<td></td>
</tr>
<tr>
<td>• Putting the correct controls in place to reduce or eliminate the risk</td>
<td>Results &amp; Discussion</td>
</tr>
</tbody>
</table>
Assigning Risk

- I offer the students 2 semi-quantitative methods to use to think about risk
- This is one of the most difficult concepts for students because they are operating with bounded rationality – their perception of risk limits their decision making abilities
- Students must provide a qualitative value and a semi-quantitative value using the methods provided
- I look for “relativity” on their assignments when I grade
Assigning Risk

- Consequences – the most probable result of the potential incident
- Exposure – the frequency of exposure to the hazard
- Likelihood – the complete sequence of events leading up to consequences will occur upon exposure to the hazard

http://www.safetyrisk.net/electronic-risk-score-calculator/
Common Assignment Task

• Prepare one liter of a 1000 ppm stock solution of copper(II) nitrate from copper solid (CAS 7440-50-8) and concentrated nitric acid (CAS 7697-37-2) for AAS standards.
Why This Assignment?

- Digestions are very common techniques still used in educational labs
- There are numerous chemical (health & physical) as well as some physical hazards to “uncover”
  - toxic gas evolved, corrosive material, oxidizing material, dilution of acid, spill response, waste incompatibility
- There is a lot of data available on the hazards associated with nitric acid (well studied)
- We use this for departmental program assessment and it is fairly easy to standardize grading with a rubric
Reflective Work

- Students submit draft JHA 1 week to 10 days after the lecture
- I will critique the draft and upload it to our electronic course system.
- Students may make an appointment with me for clarification or help
- Students have 1 week to 10 days to submit their final copy
Assessment

• A well developed rubric is used for consistent grading of expected results
  ▫ Our program goal being assessed is:
    • To acquire a thorough knowledge of laboratory methods and techniques
  ▫ One of the student learning outcomes (SLOs) for this goal is:
    • Students will evaluate and manage experimental hazards and access risk
  ▫ The criteria for meeting the goal is:
    • 70% of the students will score a sum of at least 30 points (competent) on their completed JHA assignment
Assessment Results (F14)

JHA Assignment Results 101

- 76.9% met criteria with reflection
- 62.5% met criteria

JHA Assignment Results 102

- 50.0% met criteria
<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Risk Level</th>
<th>Safety Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Obtain 1.00 g of solid copper with balance. Contact with skin, spilling</td>
<td>Low Risk (1)</td>
<td>Nitrile rubber gloves, standard eye goggles</td>
</tr>
<tr>
<td>2</td>
<td>Obtain 1.00 L HNO₃ in a beaker. Contact with skin, eyes, broken glass, oxidizer, inhalation.</td>
<td>Moderate Risk (49.5)</td>
<td>Fluorinated rubber gloves, keep away from flames/heat/combustibles, tight fitting safety goggles, avoid inhaling, dispose in appropriate waste, work in hood, use a glass funnel when transferring.</td>
</tr>
<tr>
<td>3</td>
<td>Add 1.00 g of solid copper to beaker. Nitrogen dioxide gas, rapid heat change causing glass to break.</td>
<td>Substantial Risk (60)</td>
<td>Work in hood, splash goggles, fluorinated rubber gloves, avoid inhaling, avoid skin contact,</td>
</tr>
</tbody>
</table>
Reflection

<table>
<thead>
<tr>
<th>Task Location</th>
<th>Acetone: Solvent for high vacuum</th>
<th>Task 185</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity or Job</td>
<td>Prepare a solution of copper(II) nitrate from copper(II) sulfate (CAS 75-24-7) and concentrated nitric acid (CAS 7697-37-2) for AAS standards.</td>
<td></td>
</tr>
</tbody>
</table>

**Equipment and Chemical | Received**

- Wear copper, beaker, and safety rubber gloves, work on lab bench.
- Safety goggles, face mask, and apron (after first flush), lab coat.

**Steps and Tasks**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Hazards Identified</th>
<th>Probability</th>
<th>Risk Level</th>
<th>Control or Safety Procedures for each Task / Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pour 1.5 mL of 60% copper with water.</td>
<td>Contact with skin.</td>
<td>Low Risk (L)</td>
<td>Needle rubber gloves, standard eye goggles,</td>
<td>Inadequate?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Review MSDS for copper.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Add 1.0 mL of 38% nitric acid.</td>
<td>Contact with skin, eye, nasal, inhalation,</td>
<td>Moderate Risk (M)</td>
<td>Inadequate rubber gloves,large</td>
<td>Inadequate?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>escape, avoid breathing</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Add 1.00 mL of 38% nitric acid.</td>
<td>Work in hood, aspiration, needle</td>
<td>Substantial Risk (H)</td>
<td>Inadequate rubber gloves, avoid inhaling, avoid skin contact.</td>
<td>Inadequate?</td>
</tr>
</tbody>
</table>

**Records Checklist**

- Can someone be exposed to this hazard? Yes
- Can someone be exposed to this hazard? Yes
- Can someone be exposed to this hazard? Yes, if they are not wearing any protective clothing.
## After Reflection & Revision

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Risk Description</th>
<th>Risk Level</th>
<th>Necessary Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Obtain bottle of solid copper from storage. Weigh 1.00 g of solid copper (CAS 7440-50-8) with balance. Quantitatively transfer to 500-mL beaker.</td>
<td>Skin and eye irritation due to contact with solid copper, harmful if ingested or inhaled. Broken glass.</td>
<td>Low Risk (1)</td>
<td>Nitrile rubber gloves, standard eye goggles, spill kit, lab coat,</td>
</tr>
<tr>
<td>2</td>
<td>Remove nitric acid container from storage cabinet.</td>
<td>Risk of trip/fall/slip, breaking container, spilling</td>
<td>Moderate Risk (49.5)</td>
<td>Same as above + fluorinated rubber gloves, spill kit, avoid heat/sources of ignition, organics,</td>
</tr>
<tr>
<td>3</td>
<td>Using stir bar &amp; stir plate, add enough nitric acid (CAS 7697-37-2) to the 500-mL beaker to dissolve the copper. Slowly and carefully pour the acid to avoid splashing.</td>
<td>Risk of spilling, broken glassware, contact with skin or eyes. HNO₃ is a strong oxidizer, skin corrosive, can cause serious eye/skin damage, intensifies fires, forms nitric oxides (dangerous vapors), dangerous to inhale</td>
<td>Substantial Risk (100)</td>
<td>Same as above + avoid splashing, wear splash goggles, pour slowly and carefully, perform in fume hood, avoid inhaling, contact with any part of body,</td>
</tr>
</tbody>
</table>
Common Issues Encountered

• Not being specific enough. Saying “be careful” is too vague. HOW do you need to be careful?
• Not including safety equipment that should be in the work area, i.e. emergency equipment and engineering controls.
• Not looking up glove material for nitric acid. Go to one of the glove sites on the web and look up what the recommended material is for nitric acid. What kind of goggles are needed?
• Not recognizing the hazards of nitric acid, i.e. toxic gas evolution and the possibility of violent reaction with organic materials. Waste containers must be carefully labeled and monitored.
• I want to know which mechanism you use to determine the risk level and see a quantitative descriptor as well as a qualitative one.
• It is not enough to have a spill kit – you need to know where it is and what you would do with it.
• You do not need to sign, but all information should be filled out – name, date, what are the hazards.
• DO NOT combine steps or omit steps. Think about what you are doing. You cannot just say, “Add acid to metal” – you have to say, “Remove acid bottle from storage cabinet. Poor acid into small beaker that is easily manipulated. Weigh metal. Place metal in beaker (size)? Place beaker in hood.” Etc. Each of these is a step. USE YOUR OWN WORDS. Picture yourself doing the task.
Perform a Hazard/Risk Matrix for Specific Chemicals

- ...understand the categories of hazards associated with chemicals (health, physical, and environmental)
- ...manage many types of chemical information
Concluding Thoughts

- In general, most students are actually very receptive to learning about how to practice safe chemistry through hazard analysis.
- Good students will take this assignment very seriously and meet with me to improve their hazard tools – especially the ones that they have to submit with their research proposal.
- Students often ask me why a course in chemical hygiene is not required for chemistry majors.
- Using this methodology unites chemical hygiene and chemical information in a very instructive way.
Additionally...

- A job hazard analysis can be used for a complicated (predictable) system
- The purpose of the exercises that I do with our undergraduates is to promote the shift in student thinking from simple systems (rules) to more complicated ones
- I do not expect a “perfect” tool at the end of the lesson, just a start down the path
- This can help create a cognitive category that can hopefully serve students to more safely navigate complex (unpredictable) systems encountered in the future