A Practice-Based Approach to Designing Equitable Undergraduate Science Courses

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https://uc-flc.mcdb.ucsb.edu/
Chem 1A as site of departure for Black students

Partnership with Multicultural Student Development Center

• Concerned about Black students leaving the sciences after Chem 1A

• Course led students to question ability to succeed in the sciences, particularly Black women.

“I’m a drop the class, I think. Yeah please, I think science isn’t for me. Like, I just don’t feel smart enough to continue.”

-Kristina

3 weeks into Chem 1A

Next Step: Focus groups and interviews with students
Narratives about scientific brilliance exclude many students

**Who Counts**

- STEM
- Humanities

**What Counts**

- Innate talent
- Knowing lots of information
- Quickness
- Correctness

(Leahy et al., 2015; Leonardo & Broderick, 2011; Nasir, Snyder, Shah & Ross, 2012; McGee & Martin, 2011).

(Carlone, 2004; Carlone et al., 2011).

Narratives about scientific brilliance exclude many students

**Who Counts**

- Asian
- White
- Black & Brown

**What Counts**

- Innate talent
- Knowing lots of information
- Quickness
- Correctness

(Leahy et al., 2015; Leonardo & Broderick, 2011; Nasir, Snyder, Shah & Ross, 2012; McGee & Martin, 2011).

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Students see Chem 1A as a “weeder” course

- High enrollment
- High competition
- Fast pace with wide breadth of content
- Expert knowledge holder
- White, middle-class, academic language


Science taught in classrooms incongruent with science as it’s practiced

**School Science**
- Discrete body of facts
- Content available to be memorized
- Static
- Individualized learning

**Science**
- A way of thinking
- Set of practices
- Iterative, creative process
- Collective sense-making

Carlone, 2004; Redish & Hammer, 2009; Sevian & Talanquer, 2014; Talanquer, 2015
How can we reorganize our classrooms toward equity and learning that reflects science as practiced?

Goal
Socialize students into new ways of seeing and participating in science such that they:
• develop a rich, connected, and relevant understanding of chemistry
• recognize the various ways in which they are scientifically brilliant
Organizing principles that informed the curriculum design and participation structures

- Organize curriculum around central ideas and practices of chemistry
- Engage and support students in collective chemical practice
- Recognize and leverage student strengths and experiences
- Value and call out expansive and inclusive ways to be scientifically brilliant

Building Around Big Ideas

**CHEM 1A**
**MATTER AND CHANGE**

*Potential* and *kinetic* energy considerations provide a powerful basis for explaining the macroscopic properties of matter and the ways in which matter interacts, combines, and changes on an atomic scale.

**Central Ideas and Practices**

**UNIT 1: MATTER**
Understanding Properties

**UNIT 2: ENERGY**
Predicting Change

**UNIT 3: EQUILIBRIUM**
Managing Changes

**UNIT 4: SPECTROSCOPY**
Measuring Matter

- ATTRACTIONS and MOTIONS
- A + B ⇋ AB
- Competition between ATTRACTIONS and MOTIONS
- Modifying ATTRACTIONS and MOTIONS with light
In class:
Supporting collective engagement in authentic chemical thinking and practices

Lecture

Assessments

Reflections

In-class Organization

- Class met 50 minutes 3x per week
- Multi-tiered instructional staff
- Course for non-chemistry majors
- Students with 1≤ year of HS chemistry or repeating
- 100+ students working in teams of 4-5

Collective Chemical practice
Designing in-class activity that engages students in chemical practice

- Incorporate and build upon big ideas
- Data-centered
- Invite multiple ways of engagement
- Multiple valid approaches
- Not reliant on formal scientific language

Central Ideas and Practices

Collective Chemical Practice

Student Strengths and Experiences

L10: Attractive Molecules

Today’s Question: What aspects of molecular structure affect the strength of attractions between similar molecules?

Your Task: Your team will use the data on the Intermolecular Force Cards to examine the relationship between structure and boiling point.

Examine the Relationship Between Structure and Boiling Points
Randomly divide up the cards, and then work together as a team of 4.

1. Examine the information on each of the Intermolecular Force Cards.
   - Note: You will NOT be using the solubility information today.

2. Create as many groups of cards as possible based on similarities of the substances on the cards.
   - Note: Some cards may belong to more than one group. Don’t be afraid to rearrange cards once data have been recorded.

3. Observe and Record how the boiling point changes within each group and what else differs between the cards within a group.
   - Note: In some cases, it might not be possible to strictly control for only one variable. As a team, reason together about what variable is the main factor causing the trend in boiling point.

Bringing it Together: Make Claims About Attraction and Boiling Point
Work together as a team of 4. Make sure that each member contributes one claim.

4. Construct at least 4 claims about how each variable relates to the changing boiling point. Be sure to provide evidence from your card sort. Record each claim on your Note Sheet.
   - For example: As the molar mass increases, the boiling point increases as evidenced by...
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Central Question of the day

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General Description of the day’s task

Intermolecular Force Cards
Students worked with various types of data

Data cards and tables

Images

Animations and simulations

Guiding directions, questions, and hints to support the team to work with data

Examine the Relationship Between Structure and Boiling Points

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Note Sheets provide organizational support
Challenges of Task Design

• Choosing which concept(s) to include in 40 minutes
• Choosing and designing data
• Keeping the tasks open while still providing necessary support

Supporting the Task:
Support equitable engagement in the tasks and support students’ recognition of their brilliance
Task launch: re-framing competent scientific learning

- Situate student work within the context of the course
- Orient students to any new tools needed to complete the day’s activities
- Reframe scientific thinking and learning

The Smart Things List: providing explicit language to call out collective scientific practice

1. Recognize patterns in data
2. Make connections to Coulomb’s Law
3. Control variables
4. Try multiple possibilities when grouping cards
5. Justify your ideas in ways other people can follow
6. Offer ideas even if they may not end up being right
7. Ask for people’s reasoning when they offer ideas
Support equitable sharing of resources

Today's Question:
What aspects of molecular structure affect the strength of attractions between similar molecules?

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Team leader held accountable for communicating group thinking

How do we know if something has dissociated or just dissolved?

What’s the team question?
Making student thinking public

Expansive and Inclusive Scientific Brilliance

Closing: calling out and connecting student thinking to chemistry

- Highlight brilliant scientific thinking
- Connect task and students thinking to authentic science practice

You guys are asking great questions that are getting me to think in different ways.
Challenges of supporting equitable engagement

- Re-learning how to interact with students
- Hard to intervene appropriately when we can’t hear student thinking
After class: Video lecture is designed for concept review and introduction to formal language

- Review Task
- Introduce formal chemical language
- Connect to previous concepts
- Contextualize chemistry

Central Ideas and Practices

In class

Assessments assessing scientific content and practices

Lecture

Reflections
Question Design: engaging students in chemical practice to assess content and practice learning

Central Ideas and Practices

**INTERMOLECULAR ATTRACTIONS**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Molecular formula</th>
<th>Structural formula</th>
<th>Molar mass (g/mol)</th>
<th>Boiling point</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethylene glycol</td>
<td>HOCH₂CH₂OH</td>
<td><img src="image" alt="Structure" /></td>
<td>62</td>
<td>197°C</td>
</tr>
<tr>
<td>propanol</td>
<td>CH₃(CH₂)₂OH</td>
<td><img src="image" alt="Structure" /></td>
<td>60</td>
<td>98°C</td>
</tr>
<tr>
<td>propylamine</td>
<td>CH₃(CH₂)₂NH₂</td>
<td><img src="image" alt="Structure" /></td>
<td>59</td>
<td>48°C</td>
</tr>
<tr>
<td>trimethylamine</td>
<td>(CH₃)₃N</td>
<td><img src="image" alt="Structure" /></td>
<td>59</td>
<td>3°C</td>
</tr>
</tbody>
</table>

Which statement provides the most compelling explanation of the data?

a) O–H···O is stronger than H–N···H  
b) O–H···O is weaker than H–N···H  
c) Boiling point increases with molar mass.  
d) Increasing the number of CH₃ groups decreases the boiling point.

The boiling point of ethylene glycol is much higher than the boiling point of propanol. **Draw a structure showing the interaction between ethyleneglycol molecules to explain its high boiling point.**

Communicating Science Project: an opportunity for science language learning and practice

**Expansive and Inclusive Scientific Brilliance**

**Central Ideas and Practices**

**Student Strengths and Experiences**

**Description**

- Students chose either a hormone or toxic metal salt
- Explain the chemistry of their compound to two audiences
  - Classroom Community (formal scientific language)
  - Friends and Family (informal language)
- Peer review
Unit 4: Spectroscopy

Design a post that will teach your audiences about how you can use spectroscopy on your entire compound or an element in your compound to gain information about your compound. 
Compound: Mercurous Chloride

Classroom Community

This energy must be large enough to break Coulomb's attractions between the negatively charged electrons and the positively charged nucleus. This suggests that those electrons furthest from the nucleus would require less energy to break because it has a lower attraction, whereas those in the innermost shell would be the most difficult to eject.

Friends and Family

Think of the picture above (Figure 1), where the man has a bunch of layers on. Which layers would be easiest to take off? Well, they would be the ones that are outermost or on top. To take off one of the base layers, you would need more energy because you'd have to dig through all the ones on top.

Challenges with assessment design

• Quiz and Exams
  • Finding relevant and accessible data
• Communicating Chemistry
  • Substances with complicated chemistry
  • Not all substances work well with all units
Science Skill Reflection: opportunity to define what counts as central to doing science

Which set of skills are you most interested in reflecting on for Unit 1?

- Bouncing back from setbacks
- Diligent Skepticism
- Intellectual Courage
- Collaboration
- Making Connections

Expansive and Inclusive Scientific Brilliance

When I struggle, I remind myself that encountering setbacks is a normal part of the work of a scientist.

Disagree  ☐  ☐  ☐  Agree ☐  ☐  ☐
Reflection Feedback: frame responses as shared experience and challenges

- Publicize and normalize concerns
- Explicit connection to science
- Remind students that they are taking on challenging work
- Point them to resources

“Many of you said you’re feeling nervous about holding others back by asking questions. . .”

“Wrestling with ideas, struggling, not yet knowing how to form a chemical explanation from data is a normal and important part of the work of doing science.”

Final Course Reflections

- How have your ideas about chemistry learning been changed, challenged or confirmed this semester?
- How have your ideas about what it takes to think like a chemist been changed, challenged or confirmed this semester?
Findings
Using video, survey, interview and student work to understand impact of participation

Goal
Socialize students into new ways of seeing and participating in science such that they:
• develop a rich, connected, and relevant understanding of chemistry
• recognize the various ways in which they are scientifically brilliant
Preliminary findings suggest that we are moving towards our goal

• Video data:
  • Students are engaging in scientific practice e.g. Asking chemical questions, and Identifying patterns

• Survey Data:
  • Positive shifts in how students view their relationship to science, e.g. “I am good at science”, “I feel a connection with the science community”

• Interview Data:
  • Students see learning as iteratively constructing understanding from data
  • Students have expansive, practice-centered definitions of what it means to be ‘good at chemistry’

“Before I had the preconceived notion that being a chemist took some form of innate ability and intelligence but now I know that being a chemist is more than just that. Thinking like a chemist is simply being inquisitive, hardworking, and open to new ideas. Chemistry is more than just getting the right answers, learning the concepts actually means something to me now.”

Vin, Course Reflection
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