Evidence Based Approaches to Curriculum Reform and Assessment

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Michigan State University

New Orleans, Aug 9, 2018
Who am I and why am I here?
Evidence-based Approaches to Improving Chemistry Education

Research

(Research Description PDF)

The focus of our research is to develop evidence-based approaches to teaching, learning and assessment. Our work involves a wide range of activities and methods including designing ways to assess both what students know and how they use their knowledge, developing curriculum materials, and evaluating the effects of transformation efforts both within and across disciplines.

To design effective curricula we need to know what students bring to the table both in their prior knowledge and what they are able to do with that knowledge. We also must understand how and why students develop ideas that are not scientifically sound. For example we have shown that for many students, when
Welcome to the Cooper Research Group

Recent Updates

5/5/2018 - Katie Graduated!
Katie successfully defended her dissertation and received her Ph.D. Congratulations Katie!

About Our Group
Our group focuses on improving the teaching and learning of chemistry at the undergraduate level. We use a variety of qualitative and quantitative techniques in order to examine the way that students learn chemistry and to inform the design of evidence-based curricular materials.
So what do chemistry education researchers in a chemistry department actually do?
Broadly – we try to answer the question: Why don’t students learn what we teach them?
We use theories of learning to generate evidence that can inform practice
Discipline-Based Education Research (DBER)

“DBER combines knowledge of teaching and learning with deep knowledge of discipline based STEM content. It describes the specific difficulties learners face and the specialized intellectual and instructional resources that can facilitate student understanding”

Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering. NRC 2012
How People Learn: Key Findings

• Students are not “blank slates”

• Students construct knowledge (rather than receive it intact from the instructor)

• Knowledge must be organized and contextualized

• Reflection and metacognition are important
The Framework is a synthesis of the best available evidence, based on current theories of learning.

“The framework is designed to help realize a vision for education in the sciences and engineering in which students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields.”
...and how they can connect ideas to other disciplines.

Scientific Practices

...what we want students to do with that knowledge...

Crosscutting Concepts

What we want students to know...

Core Ideas

Three-Dimensional Learning

Why Core Ideas?
Experts’ knowledge is organized into an underlying framework that reflects deep understanding of the discipline

NRC: “How People Learn” (2000)
Constructing curricula around core ideas should allow students to link and contextualize knowledge
Enduring Understandings

Anchoring Concepts (Core Ideas)
Use a table of bond energies to calculate the enthalpy change for a reaction.

Which has the highest boiling point?
A. CH₄
B. CH₃OH
C. CH₃OCH₃
D. CH₃CH₂OH
## ACS Exams Institute: Anchoring Concept Levels 1-4 for Bonding

<table>
<thead>
<tr>
<th>Level</th>
<th>Anchoring Concept II. Bonding:</th>
<th>To break a chemical bond requires an input of energy.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2</td>
<td>Enduring Understanding D.</td>
<td>To break a chemical bond requires an input of energy.</td>
</tr>
<tr>
<td>Level 3</td>
<td>Sub-disciplinary Articulations 1.</td>
<td>The energy required to break a chemical bond is the bond dissociation energy.</td>
</tr>
<tr>
<td>Level 4</td>
<td>Content Detail a.</td>
<td>Bond dissociation energy is useful at the level of individual molecules; for calculations on macroscopic quantities, the value used is the bond dissociation enthalpy.</td>
</tr>
<tr>
<td></td>
<td>Content Detail b.</td>
<td>Bond dissociation enthalpies can be used to estimate the change in enthalpy for a reaction.</td>
</tr>
</tbody>
</table>

In the ACS general chemistry curriculum map there are 263 content details each of which may be assessed.
If fragments are not connected to core ideas...

NRC: “How People Learn” (2000)
Core Ideas and Topics: Building Up or Drilling Down?

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Content knowledge (even “conceptual” knowledge) is not enough...

It has to be connected and useful
Why Scientific and Engineering Practices?

“Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements—knowledge and practice—are essential.”

Scientific and Engineering Practices

How we put knowledge to use

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations and designing solutions
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Developing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Scientific Practices
Why Cross-Cutting Concepts

“Some important themes pervade science, mathematics, and technology and appear over and over again, whether we are looking at an ancient civilization, the human body, or a comet. They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design.”

AAAS Project 2061, 1989
Crosscutting Concepts

Ideas that cut across and are important to all science disciplines

1. Patterns
2. Cause and effect
3. Scale, proportion and quantity
4. Systems and system models
5. Energy and matter conservation, cycles and flows
6. Structure and function
7. Stability and change

NRC Framework for Science Education 2012
Ideally we want to build curricula around core ideas (not topics), that provide opportunities for students to use their knowledge – by engaging in scientific practices, and that allows connections to be made across the disciplines.
## 3D-question

For this reaction \( \text{CH}_3\text{CH}_3 + \text{Cl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{Cl} + \text{HCl} \)

<table>
<thead>
<tr>
<th>a.</th>
<th>Construct chemical structures for the reactants and products.</th>
</tr>
</thead>
<tbody>
<tr>
<td>b.</td>
<td>Using your structures, identify which bonds are broken and which bonds are formed</td>
</tr>
<tr>
<td>c.</td>
<td>Explain why breaking bonds requires an input of energy from the surroundings.</td>
</tr>
<tr>
<td>d.</td>
<td>Using the table of bond energies, calculate the enthalpy change for the reaction.</td>
</tr>
<tr>
<td>e.</td>
<td>Construct an energy diagram showing the overall energy change for the reaction.</td>
</tr>
<tr>
<td>f.</td>
<td>Construct an explanation about why the energy changes during this reaction that includes</td>
</tr>
<tr>
<td>a.</td>
<td>A claim about the energy change for the reaction (exothermic or endothermic)</td>
</tr>
<tr>
<td>b.</td>
<td>The evidence you used to make this claim</td>
</tr>
<tr>
<td>c.</td>
<td>Your reasoning about why this evidence leads to the claim</td>
</tr>
</tbody>
</table>
Three-dimensional learning offers us a vision for how to help students develop more expert-like knowledge structures

NRC: “How People Learn” (2000)
Three-dimensional learning


the three dimensions should be blended together


At MSU we used the Framework to provide a coherent approach to gateway course transformation

and extending

Creating a Coherent STEM Gateway at Michigan State University

A projected funded by the AAU STEM Education Initiative Project

Further funding from NSF

Cooper et. al. Science 2016
Change model: build faculty consensus around the aims and rewards of reform through:

1. Developing a shared vision for gateway course transformation in biology, chemistry and physics
2. Developing policies and structures to support and reward reform
We convened faculty to discuss core ideas of the discipline, and what students should be able to do with these core ideas.

We held workshops and Fellowship program around 3D-Learning.
What constitutes evidence of change?
3D-learning should produce changes in both instruction and assessments


We decided to identify whether changes in assessment items and instructional behavior occurred
Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol


The 3D-LAP
3D-LAP provides criteria for each dimension

Developing and Using Models

Student is given or asked to construct a mathematical, graphical, computational, symbolic, or pictorial representation and use it to explain or predict an event, observation, or phenomenon.

1. Question gives an **event**, **observation**, or **phenomenon** for the student to explain or make a prediction about.
2. Question gives a representation or asks student to **construct a representation**.
3. Question asks student to **explain** or make a **prediction** about the event, observation, or phenomenon.
4. Question asks student to provide the **reasoning** that links the representation to their explanation or prediction.
A transformed curriculum built around core ideas, engaging students with scientific practices, and crosscutting concepts

Cooper, M.M. Klymkowsky, M.W. “Chemistry, Life, the Universe and Everything (CLUE): A new approach to general chemistry, and a model for curriculum reform” J Chem Educ, 2013, 90, 1116-1122; DOI: 10.1021/ed300456y
• Energy Connections and Misconnections Across Chemistry and Biology 2018, doi: 10.1187/cbe.17-08-0169,
• When do students recognize relationships between molecular structure and properties? A longitudinal comparison of the impact of traditional and transformed curricula. Chemistry Education Research and Practice. 2016, 17, 365-380, DOI: 10.1039/C5RP00217F
• Are Noncovalent Interactions an Achilles Heel in Chemistry Education? A Comparison of Instructional Approaches. J. Chem. Educ., 2015, DOI: 10.1021/acs.jchemed.5b00619
• College chemistry students’ understanding of potential energy in the context of atomic-molecular interactions” J. Res. Sci Teach. 2014, 51. 6, 789-808, DOI 10.1002/tea.21159
We coded 4020 questions using the 3D-LAP over four years (Year 0 to Year 3)

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Sections Offered</th>
<th>Unique Instructors</th>
<th>Unique Exams</th>
<th>Questions Coded</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem I and II</td>
<td>49</td>
<td>21</td>
<td>32</td>
<td>718</td>
<td>93</td>
</tr>
<tr>
<td>Phys I and II</td>
<td>78</td>
<td>35</td>
<td>34</td>
<td>479</td>
<td>230</td>
</tr>
<tr>
<td>Bio 1</td>
<td>34</td>
<td>20</td>
<td>40</td>
<td>1,705</td>
<td>184</td>
</tr>
<tr>
<td>Bio 2</td>
<td>24</td>
<td>9</td>
<td>28</td>
<td>528</td>
<td>83</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>185</strong></td>
<td><strong>87</strong></td>
<td><strong>134</strong></td>
<td><strong>3,430</strong></td>
<td><strong>590</strong></td>
</tr>
</tbody>
</table>
Fraction of three-dimensional assessment items over time

- Year 0
- Year 1
- Year 2
- Year 3

Fraction of exam points that are 3D

= 200 students
Fraction of three-dimensional assessment items over time
This decrease in DFW rate practically translates to approximately **740 more students** earning a grade of 2.0 or above in Year 3 compared to Year 0.

Students had significantly (p < 0.05) higher average final grades in year 3 than in year 0.
So more students pass the course – do they learn anything?
We have given the ACS conceptual exam to CLUE students in both large and small class sections –

• CLUE students score above the national average
• There is no difference by class size or institution
• Even though the exam “covers” more (and different) material
We have also published a number of papers on our findings:

- Energy Connections and Misconnections Across Chemistry and Biology *2018*, doi: 10.1187/cbe.17-08-0169,
- College chemistry students’ understanding of potential energy in the context of atomic-molecular interactions” *J. Res. Sci Teach.* *2014,* 51. 6, 789-808, DOI 10.1002/tea.21159
Summary

• Discipline Based Education Research can provide theory and evidence that can inform instruction
• Curriculum design should focus on core ideas and scientific practices
• At MSU we have implemented these ideas in gateway courses
• We have increased average grades and retention for all demographics
• We also have a LOT of evidence of improved student learning...
Discipline-Based Science Education Research vs

Private Empiricism

Private empiricism – where we believe something because of our own personal experience – is not appropriate for scientists, yet when it comes to education, personal experience seems to be an acceptable substitute for evidence. Unfortunately, most scientists’ beliefs about education are rarely based on objective evidence, but rather on what they imagine to be true. While personal experience in the classroom can give valuable insights, it is not data

Data-Driven Education Research, Cooper, M. M. *Science*, August 2007: p. 1171
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