BeSocratic

Melanie M. Cooper

TRUSE Conference 2012
Acknowledgements

NSF
Dreyfus Foundation
Cengage
<table>
<thead>
<tr>
<th>Year</th>
<th>%DFW</th>
<th>ACS %ile</th>
<th># students</th>
<th># DFW</th>
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<tbody>
<tr>
<td>2001</td>
<td>23</td>
<td>61</td>
<td>1200</td>
<td>270</td>
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<tr>
<td>2002</td>
<td>30</td>
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<td>2004</td>
<td>44</td>
<td>75</td>
<td>1429</td>
<td>625</td>
</tr>
</tbody>
</table>
Reforms

- Weekly meetings to negotiate “big ideas” and learning outcomes and assessments (backward design)
- Reduce class size (to about 100 from 180)
- Remove content (~30%)
- Add “active” learning (group work, clickers etc)
- Each faculty member uses their own notes/class management style
  - there is typically no difference in grade distributions
## Success!

<table>
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<td>2006</td>
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<td>72</td>
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<td>2007</td>
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<td>150</td>
</tr>
<tr>
<td>2008</td>
<td>18</td>
<td>79</td>
<td>1300</td>
<td>230</td>
</tr>
<tr>
<td>2009</td>
<td>15</td>
<td>75</td>
<td>1570</td>
<td>236</td>
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</table>

We can go home
Well – not so fast...

What happens to the potential energy when you bring two hydrogen atoms together?

“The potential energy goes up ... when you break a bond it releases energy”
Energy changes and bonding

<table>
<thead>
<tr>
<th>% Students by type with bond energy misconceptions</th>
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<tbody>
<tr>
<td>Chemistry level (#)</td>
</tr>
<tr>
<td>General Chemistry (77)</td>
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<tr>
<td>Inorganic (13)</td>
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<td>Organic (172)</td>
</tr>
<tr>
<td>Analytical (35)</td>
</tr>
<tr>
<td>Physical (16)</td>
</tr>
<tr>
<td><strong>Graduate Students (21)</strong></td>
</tr>
<tr>
<td><strong>Post docs (25)</strong></td>
</tr>
</tbody>
</table>
Jane (OC2): What are intermolecular forces?

Jane: “I think the intermolecular force is talking about, is talking only in liquid phase.”

Interviewer: “How is ice structured then? Like what holds it together?”

Jane: “Probably the, the I mean the, since the temperature is very low, umm the activity of each molecule is, is very low. So they are umm, they’re very stable at where they are.”
Brittany (GC2): when water boils ...

“...all those bonds are broken up it’s like pieces of oxygen. It’s like particles of oxygen and hydrogen and that can mix with anything so it’s not technically a water molecule anymore because it’s all broken up I guess. I don’t know.”
Jill (Organic 2)

How boiling $H_2O$ works

Student: Like a bunch of them together would be more like water and I guess they would, and they’d all be connected together but I guess like if they were a gas they would, some of them would split up.

Interviewer: Ok so, so you were talking about like this part would split up, whatever’s connecting the waters?

Student: Yeah like, yeah like the bond between two water molecules would break.
In chemistry there is rarely a single problem or “misconception”

• Naïve ideas (p-prims)
  – Atoms get larger when heated
• Didaskalogenic (instructor induced)
  – Bonds form because atoms “want” octets
• Heuristics
  – Like dissolves like
• Inappropriate application of knowledge
  – Steric hindrance affects boiling points
• Misuse of terminology
  – A Hydrogen bonding isn’t actually a bond
• Representational problems
  – Inability to decode meaning from structures
• Inappropriate Models
  – Use of Bohr model of atom to describe bonding
In chemistry there is rarely a single idea or concept – everything is related.

- Misuse of terminology
- Naïve ideas
- Inappropriate application of knowledge
- Heuristics
- Representation problems
- Didaskalogenic ideas

Output
Student mental model

Heuristic

Naive

Didaskalogic

Representation of problems
Student mental model

Naive

Didaskalogenic

Inappropriate concepts

Terminology

Heuristic
Student mental model

Representation problems

Terminology misapplication

Naïve ideas

Didaskalogenic

heuristic
Student mental model

Inappropriate application

Terminology misapplication

Naïve ideas

Didaskalogenic

heuristic
How can we help students develop deeper more coherent conceptual understanding?

And how will we know when we have done that?
The role of assessment

“to educate and improve student performance, not merely to audit it”

Assessment drives the enacted curriculum
Introductory classes

• Typically large (and growing larger)
• Novice learners
• Standardized (publisher generated) curricula and materials
• Often where future high school teachers learn content
  – And, by example, pedagogy
It appears that sorting students is more important than teaching them valuable, transferrable knowledge.

What are we willing to accept as evidence of learning?

The nature of the assessments may actually be affecting what is taught (and certainly what is learned)

How can we assess what we say we value? (not testable trivia)
What do we value?
NRC Framework: Science and Engineering Practices

• Asking Questions and Defining Problems
• Developing and Using Models
• Planning and Carrying Out Investigations
• Analyzing and Interpreting Data
• Using Mathematics and Computational Thinking
• Constructing Explanations and Designing Solutions
• Engaging in Argument from Evidence
• Obtaining, Evaluating, and Communicating Information

http://www.nextgenscience.org/
Next Generation Science Standards - combine content with a science practice:

• **Use models to explain** that atoms (and therefore mass) are conserved during a chemical reaction

• **Construct arguments** for which type of atomic models best explains a particular property of matter

http://www.nextgenscience.org/
How will these kinds of performance expectations be assessed?
BeSocratic

Besocratic.clemson.edu
Constructing vs “recognizing”

Computer interfaces impose constraints

Emerging evidence that drawing, writing and gesturing are important for learning

- Ainsworth, Prain, & Tytler,. 2011,, *Science*, 1096
- Trujillo, Cooper & Klymkowsky. 2012.. *BAMBED*, in press.
BeSocratic

• Allows free form input – graphs, chemical structures, diagrams, gestures, and text
• Provides tiered contextual Socratic feedback
• Collaboration between chemistry, biology, physics, math, computer science
BeSocratic: Student interface

Please draw a graph to show how the potential energy changes as an atom of hydrogen and an atom of fluorine approach each other.

Potential Energy

Internuclear distance
BeSocratic: Author interface
The arrow always starts on an electron source (a Lewis base) and ends on an electron sink (an a Lewis acid).

Put your finger on the electron source and trace the path of the electrons from the source to the electron sink.

When finished, click NEXT to continue.
Activity is made up of 1 or more Activity Steps
Activity Step is composed of 1 or more Modules
BeSocratic Modules

- Image
- Drawing
- Text Box
- Video
- Text
- 3D Model
- Chalkboard
- OrganicPad
- Graph
- GraphPad
BeSocratic Modules

- Image
- Drawing
- Text Box
- Video
- Text
- 3D Model
- Chalkboard

Provide Feedback

- OrganicPad
- Graph
- GraphPad
Graphs: Author Interface
Now back to student problems!
We used OrganicPad to see how students develop the ability to draw Lewis structures.

Organic chemistry students can’t draw Lewis structures

Average Success Rate vs. Number of Atoms

Average Success Rate (%) vs. Number of Atoms

The transition from one to two carbon atoms!

Meaningful learning

The road from

C₂H₆O → H—C—C—O—H

Properties:
(Liquid - with high boiling point (H-bonding), both acidic and basic properties, susceptible to nucleophilic attack when protonated, etc).

Is difficult, complex, counter-intuitive, and all too often meaningless to many students

Our hypothesis: teaching for meaningful learning should help students improve their ability to construct \textbf{and use} Lewis structures.
Learning Progressions

Corcoran. Mosher, and Rogat, 2009
CLUE approach to Structure and Function: A learning progression

- Introduce Physical Properties
- Use Lewis structures to determine properties
- Introduce More Complex structures
- Transition 2D → 3D
- Transition 3D → 2D
- Understand 3D Structure (models)
- Relate to molecular structure
- Bonding and energetics

Cooper et. al. J Chem Educ 2012
Structure-Properties

H₂O → H–O–H → Lewis Structure → Predicts properties

Energy of interactions
Molecular Formula

Deduce type and relative strength of intermolecular forces

Identification of molecular polarity

δ−O → Hδ+

Identification of individual bond polarities

Molecular shape (bent)

Electron Pair Geometry (tetrahedral)

Cooper et al. CERP 2012
How to assess this complex construct?
The same cohort of control and treatment students were followed for two whole years.

<table>
<thead>
<tr>
<th></th>
<th>Fall Semester</th>
<th>Spring Semester</th>
<th>After 2 semester of O-Chem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (Traditional)</td>
<td>N = 120</td>
<td>N = 83</td>
<td>N = 32</td>
</tr>
<tr>
<td>Treatment (CLUE)</td>
<td>N = 93</td>
<td>N = 56</td>
<td>N = 24</td>
</tr>
</tbody>
</table>
Comparison of pre-test assessments: Fall 2010

<table>
<thead>
<tr>
<th>Pre-Instruction Assessments</th>
<th>Control Group Mean</th>
<th>Treatment Group Mean</th>
<th>p-value</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAT Composite</td>
<td>1186</td>
<td>1190</td>
<td>.76</td>
<td>3861</td>
</tr>
<tr>
<td>TOLT</td>
<td>8 (out of 10)</td>
<td>8 (out of 10)</td>
<td>.35</td>
<td>3650</td>
</tr>
<tr>
<td>Intellectual Accessibility – ASCIv2</td>
<td>46%</td>
<td>45%</td>
<td>.63</td>
<td>3800</td>
</tr>
<tr>
<td>Emotional Satisfaction – ASCIv2</td>
<td>56%</td>
<td>56%</td>
<td>.95</td>
<td>3945</td>
</tr>
<tr>
<td>Motivation – MSLQ</td>
<td>79%</td>
<td>80%</td>
<td>.69</td>
<td>3827</td>
</tr>
</tbody>
</table>
Note: all activities relating to this assessment were conducted AWAY from the lecture sections (in lab). None of the researchers were involved in the collection of the data.

*Development and Assessment of a Molecular Structure and Properties Learning Progression, Cooper, Underwood, Hilley & Klymkowsky, “in press”*
Comparison of Lewis Structure drawing ability

- **Average for all 12 (post-Fall)**: Control Mean = 42%, Treatment Mean = 54%, p-value = .006, r = .19
- **7 Harder structures (post-Fall)**: Control Mean = 34%, Treatment Mean = 57%, p-value < .001, r = .34
- **Average for all (end of Spring)**: Control Mean = 37%, Treatment Mean = 70%, p-value < .001, r = .6
- **2 Most difficult structures (end of Spring)**: Control Mean = 11%, Treatment Mean = 41%, p-value < .001, r = .43
Is this an instructor effect?

Fall 2009 Data: All students in traditional sections

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean % Correct</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor “A”</td>
<td>56</td>
<td>65.8</td>
<td>0.997</td>
</tr>
<tr>
<td>(traditional)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Group</td>
<td>98</td>
<td>66.2</td>
<td></td>
</tr>
</tbody>
</table>
CLUE students appear to have some lasting improvement - but do they know what Lewis structures are for?
We have developed a survey instrument

Implicit Information from Lewis Structures Instrument (IILSI)

Development and Assessment of a Molecular Structure and Properties Learning Progression, Cooper, Underwood, Hilley & Klymkowsky, “in press”
End of 1st Semester  End of 2nd Semester

CLUE (N=24)  Traditional (N=32)

Effect Size: 0.26, 0.30, 0.28, 0.32
We are also analyzing a trove of qualitative data...
Please describe in detail what you think is happening at the molecular level for this reaction?

Control Students “Warrants”

- Thus the nucleophile (with its lone pairs) reaches out to attack the B.
- B is combining with the electrons on the N so that they can both from an octet.
- The lone pair on the nitrogen forms a bond to the boron in the fourth bonding area, although boron usually is content with only having three bonds.
- This species is charged and could undergo a reaction to dissociate back into the other species on the left.
- Entropy decreases as a covalent bond is formed.

\[
\begin{align*}
\text{H} & \quad \text{N} \quad \text{H} \\
\text{H} & \quad \text{F} \quad \text{B} \quad \text{F}
\end{align*}
\]
Using BeSocratic for making a scientific explanation or argument

Students answer a question, and are then taken through the steps:

1. making a claim
2. Providing data or evidence
3. Linking the two with an explanation
BeSocratic has built-in coding capabilities

Based on the Lewis structures of ammonia (NH₃) and water (H₂O) below, which one of them is a stronger acid? Please explain your reasoning.
Now let's look at two slightly more complicated compounds. Based on the Lewis structures of methanol (CH3OH) and methanamine (CH3NH2) below, which one of them is a stronger base? Please explain your reasoning.

Methanamine is a stronger base because it contains more hydrogen atoms. Bases are proton donators so because Methanamine has more protons to donate it is a stronger base.
Students are then provided with their initial answer and asked to edit it.
As you go across a row, the atomic radius decreases.

As you move from lithium to flourine on the periodic table, the atomic radius becomes smaller because of the increase in effective nuclear charge of the atoms.
Please explain the trend in atomic radius across a row in the periodic table.

As you go across a row, the atomic radius decreases. This is because the number of protons increases as you go across a row. The more protons that are present, the stronger pull the nucleus has on the electrons. Therefore, the radius is smaller because the electrons are pulled in closer to the nucleus.

As you move from lithium to flourine on the periodic table, the atomic radius becomes smaller because of the increase in effective nuclear charge of the atoms. The increase in the number of protons will pull the electrons closer to the nucleus.
Explain the trend in atomic radius across the periodic table.

![Bar Chart]

- **Initial Response**
  - Claim: 14 students
  - Claim & Data: 4 students
  - Claim, Data & Warrant: 2 students

- **After the Activity**
  - Claim: 12 students
  - Claim & Data: 4 students
  - Claim, Data & Warrant: 4 students

- **Additional Question**
  - Claim: 2 students
  - Claim & Data: 4 students
  - Claim, Data & Warrant: 14 students
Which is the strongest acid (NH$_3$ or H$_2$O) why?

Q1 initial response

- No Claim
- Claim Only
- C+D
- C+D+W

Percentage of Students

- CLUE 102
- Trad 102
Which is the strongest acid (NH₃ or H₂O) why?

Q1 edited response

<table>
<thead>
<tr>
<th>Percentage of Students</th>
<th>No Claim</th>
<th>Claim Only</th>
<th>C+D</th>
<th>C+D+W</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLUE 102</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trad 102</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

* indicates significant difference.
Which is the strongest acid (CH$_3$NH$_2$ or CH$_3$OH) why?

Q2 response

<table>
<thead>
<tr>
<th>Percentage of Students</th>
<th>CLUE 102</th>
<th>Trad 102</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Claim</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Claim Only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C+D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C+D+W</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Is the claim correct? (which is a stronger acid?)

Correctness of claim

- Q1 ini: 50%
- Q1 edt: 50%
- Q2: 40%

Trad 102
Is the claim correct?

Correctness of claim

Q1 ini

Q1 edt

Q2

Trad 102

CLUE 102

***

***

***
We are working on:

BeSocratic analysis of graphical, text & time data:

Clustering analysis and Hidden Markov Modeling

to predict and intervene with unproductive approaches
Easy -> Harder
Summary

• Conventional tests may be misleading about what students know
• Merely changing the pedagogical approach is not enough (but will produce some effect)
• Misconceptions are rarely simple – but may be a result of a dynamic set of disconnected and incoherent things
• Designing courses and curricula with explicit links both within and among the major core ideas may product more transfer and lasting learning
• Using formative assessments that require students to construct and explain their understanding may help students develop valuable skills