“What do we know about how students learn organic chemistry?”

Literature Seminar
Olivia M. Crandell
Wednesday, February 1, 2017
Visualization and Spatial Ability

Laboratory

Alternative Conceptions
Confusing electronegativity with negative charge

Conflating nucleophilicity with basicity

Stability of products vs. feasibility of reaction mechanism

Electron-pushing formalism and mechanisms

Electron-pushing formalism and mechanisms

- Faculty Ideas
- Student use as a tool
- Student understanding
- Implications
Research Methods

Quantitative

“What are students’ success rates for using and interpreting the EPF?”

Qualitative

“How do students construct their knowledge of alkyl halide reactions?”

Research Methods

Quantitative
Investigates if a phenomenon occurred

Qualitative
Investigates why a phenomenon occurred

What is a mole?

Mixed Methods

How do students use their concept of a mole in problem solving?

“What is your definition of ‘mechanistic reasoning using the electron-pushing formalism?’”

“What types of tasks can one solve using this type of reasoning?”

“What skills are required to develop proficiency in proposing and interpreting mechanism?”

Open-ended questions  

Pilot survey  

Revised survey  

What is the BEST definition for mechanistic reasoning using the electron-pushing formalism (arrow-pushing)?

☐ Explicit consideration of the movement of electrons and atoms, and the formation of intermediate structures, in explaining the outcome of a chemical reaction.

☐ A working hypothesis that allows one to rationalize or predict the outcome of a given transformation by representing the shifting of single electrons or electron lone pairs. This is mostly based on our established body of knowledge of mechanistic organic chemistry, but can occasionally venture into more exotic hypotheses.

☐ Understanding as much as possible about what happens between A and B in the reaction $A \rightarrow B$, including the distinctions between thermodynamic and kinetic control in their many manifestations.

☐ The representation of the movement of electrons and atoms to demonstrate the stepwise transformation of a set of reactants into the products of a chemical process. The resulting mechanisms are “working hypotheses” based on established paradigms of chemical reactivity.

☐ The predictive/deductive process for predicting/interpreting the results of molecular transformations that occur by electron redistribution during reactions.

☐ Other, please specify
To what extent is each of the following skills important for proficiency in mechanistic reasoning using the electron-pushing formalism (arrow-pushing)?

<table>
<thead>
<tr>
<th></th>
<th>Very Important</th>
<th>Important</th>
<th>Neutral</th>
<th>Unimportant</th>
<th>Very Unimportant</th>
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</thead>
<tbody>
<tr>
<td>Valence</td>
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<td>Electronegativity</td>
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<td>M. O. Theory</td>
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<td>VSEPR</td>
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<td>Drawing Lewis Structures</td>
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<td>Bond Polarity</td>
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<tr>
<td>Accounting for Electrons</td>
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<tr>
<td>Determining Areas of High/Low Electron Density</td>
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</tbody>
</table>
Table 2. Survey Choices for the Definition of Mechanistic Reasoning Using EPF during Phase Two of the Study

<table>
<thead>
<tr>
<th>Option</th>
<th>Number&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Definition&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>8</td>
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<td>29</td>
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<td>3</td>
<td>0</td>
<td>Understanding as much as possible about what happens between A and B in the reaction A → B, including the distinctions between thermodynamic and kinetic control in their many manifestations.</td>
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<td>4</td>
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<td>13</td>
<td>Other</td>
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<sup>a</sup>Number indicates the number of individuals choosing that definition out of a total of 103 participants. <sup>b</sup>Option 4 is the hybrid of several of the responses from phase one. Those who chose “Other” were asked to enter a free-response comment.
“The representation of the movement of electrons and atoms to demonstrate the stepwise transformation of set of reactants into the products of a chemical process. The resulting mechanisms are ‘working hypotheses’ based on established paradigms of chemical reactivity.”

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Table 3. Survey Choices for the Definition of Mechanistic Reasoning Using EPF during Phase Three of the Study

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<th>Option</th>
<th>Number&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Definition&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
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<td>28</td>
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<td>2</td>
<td>47</td>
<td>The representation of the movement of electrons and atoms to demonstrate the stepwise transformation of a set of reactants into the products of a chemical process. The resulting mechanisms are “working hypotheses” based on established paradigms of chemical reactivity.</td>
</tr>
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<td>3</td>
<td>51</td>
<td>Electron-pushing arrows (EPAs) show the change in disposition of electrons as bonds are formed and broken during a chemical reaction. To the greatest extent possible, EPAs conform to patterns established by known mechanisms and reflect an understanding of partial or formal charges that may exist among the reactants and intermediates.</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>The use of Lewis structures and arrows to show electron motion to rationalize hypothetical, lowest energy pathways between stationary states in chemical reactions.</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>Electron pushing defines clearly the changes in bonding that occur in each step in a mechanism, and the practice of electron pushing teaches what constitutes reasonable mechanistic steps. Mechanistic reasoning using electron pushing is the idea that each step in a mechanism has to be a reasonable step.</td>
</tr>
</tbody>
</table>

<sup>a</sup>Number indicates the number of individuals choosing that definition out of a total of 170 participants. <sup>b</sup>Only options 1 and 2 were retained from the original survey.
“Electron-pushing arrows (EPA) show the change in disposition of electrons as bonds are formed and broken during a chemical reaction. To the greatest extent possible, EPA’s conform to patterns established by known mechanisms and reflect an understanding of partial or formal charges that may exist among the reactants and intermediates.”

Common Themes in the Definitions

Chemical Principles

EPF

Electronegativity
Accounting for electrons
Drawing Lewis structures
Lewis acid-base theory
Recognition of nucleophiles and electrophiles

Predict and explain products
Explain regio- and stereochemical outcomes

Constructivism

Constructivism

“Knowledge is constructed in the mind of the learner.”

Constructivism

Chemical Principles

EPF

Electron-pushing formalism and mechanisms

Faculty Ideas

Student use as a tool

Student understanding

Implications
Language of mechanisms: exam analysis reveals students’ strengths, strategies, and errors when using the electron-pushing formalism (curved arrows) in new reactions

Alison B. Flynn* and Ryan B. Featherstone

Filling in arrows

Predicting products

**Example of student work shown in pink**
Filling in arrows

**Example of student work shown in pink**

Average student success score = 72%

It seems that most students can draw arrows absent of content knowledge
Predicting Products

**Example of student work shown in pink

Average student success score = 55%

Drawing a product is more difficult

We shouldn’t be surprised by this
...and how they can connect ideas to other disciplines.

Scientific Practices

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

Core Ideas

What we want students to know...

Fundamental Chemical Principles

Using models

Three-Dimensional Learning

Why separate content from the formalism?

“In principle, if students are “fluent” in chemistry’s language, they should have lower cognitive load demands and will be positioned to more deeply analyze subsequent reactions.”

Critique

What are student’s success rates for using and interpreting the EPF?

Does teaching the EPF without content help students develop a deeper understanding of mechanisms?
Student Understanding

Student reasoning with alkyl halide reactions

How do students construct their knowledge of alkyl halide reactions?
S_N2 inverts the stereochemistry

9 (of 22) students got this correct

11 (of 22) students missed the stereochemistry
“I think the **stereochemistry would be the same**, I think it’s just the **iodine switches with the bromine.**” – Mark

“I’m just getting rid of Br ‘cause **we always get rid of Br**…” – Susan
Why is iodide a strong nucleophile?

Iodide is a strong nucleophile.

Why do polar aprotic solvents facilitate $S_N2$?

Polar aprotic solvents facilitate $S_N2$. 

Limitations
Implications for Instruction

Make ‘use of chemical principles’ a classroom expectation

Encourage students to see the meaning of the EPF and mechanisms

Student Understanding

Student reasoning with alkyl halide reactions

Case study of an “interesting” student

Graduate student understanding
What can we do about ‘Parker’? A case study of a good student who didn't ‘get’ organic chemistry

Trisha L. Anderson and George M. Bodner*

Received 1st November 2007, Accepted 8th March 2008
DOI: 10.1039/b806223b

Attended class
Studied regularly
Read the text
Successful in general chemistry
“Then I hit chapter five and it was like hitting a brick wall. And, uh, but I thought I could still get through it the same way, so I tried that and I found it didn’t, wasn’t working...” — Parker

“[I] don’t understand why, and that’s the way it is for a lot of my friends that I talk to.” – Parker

“They’re like, well, I just memorized it. I don’t know how to explain it to you. And, I want the whys... it should come down to the whys.” – Parker

Chemical Principles EPF
“We believe that Parker’s inability to view the letters, lines, dots, and arrows with which organic chemists communicate as true symbols contributed greatly to his feeling that organic chemistry contributed greatly to his feeling that organic chemistry was not about ‘why’.”

“Why do you always pick the ones [questions] with diagrams [chemical symbols]? ... I like the word ones better. I can figure those out.” – Parker

“There has to be reasons why, and I feel like his [the professor’s] diagrams don’t teach that.” – Parker

Chemical Principles

EPF
Rule-based learning

“When I see something that is important, like a rule or something, I highlight it.” – Parker

“So, the problem I’m having is there are so many rules I’m struggling to associate which rules go with which, cause I’m bad at memorization.”
- Parker

“Experts’ knowledge cannot be reduced to sets of isolated facts or propositions...”

“Experts notice features and meaningful patterns of information that are not noticed by novices.”

Implications for Teaching

General chemistry vs. Organic chemistry

Applying chemical principles

Explicit becomes implicit

Process oriented thinking

“It Gets Me to the Product”: How Students Propose Organic Mechanisms

Gautam Bhattacharyya and George M. Bodner*
Department of Chemistry, Purdue University, West Lafayette, IN 47907; *gmbodner@purdue.edu
Warm-up problem

“I hope this is right. It seems right to me. It’s **basically just playing around**. It’s the hardest part I think when you’re doing these things because I’m so intent on getting from reactant to product and if I see that something is not working **I’ll try and force it to work** instead of just letting my mind go and play with what you have.” – Jen
“Um, well I just try to force it to work. That way I can get it to work. I don’t know if it’s always right or not.” – Marion

Chemical Principles

EPF
“Teaching and learning are not synonymous; we can teach, and teach well, without having the students learn”

“Knowledge is constructed in the mind of the learner.”

How can we help students bridge this gap?
Implications for Research

What should we teach first? Principles or the EPF?

Does being able to explain “why” actually improve the connection between the EPF and chemical principles?

How do we help students away from Rule-Based learning?
Acknowledgements

Dr. Melanie Cooper
Dr. Lynmarie Posey

Cooper Research Group

Dr. Justin Carmel  Dr. Ryan Stowe
Katie Kohn  Oscar Judd
Chris Minter  Keenan Noyes
Table 1. Curriculum Overview for the First Two Organic Chemistry Courses

<table>
<thead>
<tr>
<th>Month</th>
<th>Section</th>
<th>Topic</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Lewis &amp; line structures, formal charge, electronegativity, MO theory, etc.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Physical properties of organic compounds</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>Conformational analysis: Newman projections, cyclohexane, etc.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>Stereochemical analysis: isomerism, chirality, etc.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>Mechanisms, EPF, resonance</td>
<td><img src="image" alt="" /></td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>Acid-base reactions</td>
<td><img src="image" alt="" /></td>
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<tr>
<td>2</td>
<td>7</td>
<td>π electrophiles with no LG</td>
<td><img src="image" alt="" /></td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>π nucleophiles: alkenes &amp; alkynes</td>
<td><img src="image" alt="" /></td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>π nucleophiles: aromatics</td>
<td><img src="image" alt="" /></td>
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</tbody>
</table>

Transformed OC by Flynn