Bioliteracy, Concept Inventories, & beyond...
Bioliteracy, Concept Inventories, & beyond...

or

how I evolved from a simple scientist to someone interested in effective science education.
time line

education ↘
  ↘
  ↘
  ↘
  ↘

job

undergraduate, graduate, post-doc

↓

today
time line

education

| undergraduate |
| graduate    |
| post-doc    |

no training in teaching quantum tunneled through the educational system

job

today

Thursday, April 28, 2011
time line

education

job \{ assistant professor

today
education

job

assistant professor

no training in teaching assigned to teach cell biology!

today
time line

education

job

{ assistant professor

no training in teaching assigned to teach cell biology!

redesigned cell biology lab, around phototaxis in amoeba

today
time line

education

↓

job

{ assistant professor

↓

no training in teaching assigned to teach cell biology!

↓

redesigned cell biology lab, around phototaxis in amoeba

↓

discovered practical constraints on large lab courses

today
education
↓
job
↓
assistant professor
↓
no training in teaching assigned to teach cell biology!
↓
redesigned cell biology lab, around phototaxis in amoeba
↓
discovered practical constraints on large lab courses
↓
concentrated on science

Thursday, April 28, 2011
time line

education

job

associate professor

today
time line

education
↓
job
↓
associate professor
↓

As asked to take part in The Dynamic Cell (CD-ROM) virtual reality tour of cell

today
education ↓ job ↓

associate professor

today

Asked to take part in The Dynamic Cell (CD-ROM) virtual reality tour of cell

Developed “Working with the literature” for Lodish et al (4th ed).
time line

education

job

\{ professor \\

 today
time line

education

↓

job

↓

↓

↓

↓

{ professor

↓

dissatisfaction understanding of independent study students

today

Thursday, April 28, 2011
time line

education

job

{ professor

Developed and taught Biofundamentals course with associated virtual laboratory

dissatisfaction understanding of independent study students

today
time line

education

↓

job

↓

professor

{→

Developed and taught Biofundamentals course with associated virtual laboratory

what is fundamental?

dissatisfaction understanding of independent study students

today
Thursday, April 28, 2011

time line

education

job

professor

what is fundamental?

Developed and taught Biofundamentals course with associated virtual laboratory

dissatisfaction understanding of independent study students

Began work with Kathy Garvin-Doxas on BCI project

today
Thursday, April 28, 2011

time line

education
↓
job
↓
professor
↓
today

Developed and taught Biofundamentals course with associated virtual laboratory

what is fundamental?

dissatisfaction understanding of independent study students

what do students really know?

Began work with Kathy Garvin-Doxas on BCI project
Course design, in general ...

Klymkowsky, 2011. Getting serious about science education. ASBMB Today, Jan
Course design, in general ...

- Start here!
- Define
- Course learning goals
- We may need to "get real" & redefine our prerequisite courses: their relevance & effectiveness
- This could lead to a reexamination of which implies that we know
- This helps us recognize the foundational concepts and skills we assume students already have
- Did the students master the materials?
  - If not, we need to introduce, review, or reteach the needed skills & concepts
  - We probably should check if not, we need to
- We probably should check whether students actually have the necessary knowledge and skills.
- This all takes class time, we may have to reconsider

Klymkowsky, 2011. Getting serious about science education. ASBMB Today, Jan
Biofundamentals

http://virtuallaboratory.colorado.edu/Biofundamentals/

no book (on-line) tutorials (in class) questions to answer
• What does it mean to cheat, in terms of sexual selection - is the "cheating" organism actually being consciously deceptive?
• What types of "cheating" behavior do females use with males; or males with females?
• Is Devendra Singh right about "mating budgets"?
• What are the costs involved when a male tries to monopolize one or more females? what are the advantages?
• Does sexual selection have to occur in both sexes?
• What limits runaway selection?

http://virtuallaboratory.colorado.edu/Biofundamentals/
Two-Dimensional, Implicit Confidence Tests as a Tool for Recognizing Student Misconceptions

By Michael W. Klymkowsky, Linda B. Taylor, Shana R. Spindler, and R. Kathy Garvin-Doxas
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• penalty for being “confidently” wrong

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- small reward for recognizing “not knowing”
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- small reward for recognizing “not knowing”
- possible to be “right” if justification validates choice
- allows for more ambiguous questions
- emphasizes (to students) importance of thinking / transfer

http://virtuallaboratory.colorado.edu/Biofundamentals/
Teaching is like evolution...
Teaching is like evolution...
without selection (that is authentic assessment) things drift.
Ersatz Learning, Inauthentic Testing

John F. McClymer & Lucia Z. Knoles
Assumption College
(available @ http://spot.colorado.edu/~klym)
There is "a damaging collusion between students on the one hand and faculty on the other — a collusion in which students agreed to accept bad teaching provided that they were given bad examinations."
– Peter Kennedy
What types of authentic assessment are available?
What types of authentic assessment are available?

• Socratic dialog (formative) / interrogation (summative)
What types of authentic assessment are available?

- Socratic dialog (formative) / interrogation (summative)
- Watch someone perform a task
What types of authentic assessment are available?

- Socratic dialog (formative) / interrogation (summative)
- Watch someone perform a task
- Responses to well designed essay questions
What types of authentic assessment are available?

- Socratic dialog (formative) / interrogation (summative)
- Watch someone perform a task
- Responses to well designed essay questions
Example, why the “central dogma” important?

DNA
↓ ↑
RNA
↓ ↑
protein
Example, why the “central dogma” important?

DNA
↓ ↑
RNA
↓ ⊗
protein

Makes
Lemarckian
evolution
problematic
Example, why the “central dogma” important?

DNA $\downarrow \uparrow$ RNA $\downarrow \uparrow$ protein

Makes Lemarckian evolution problematic

Essay answer analysis
Example, why the “central dogma” important?

DNA ↓ ↑ RNA ↓ ↑ protein

Makes Lemarckian evolution problematic

Essay answer analysis
Example, why the “central dogma” important?

DNA ↓ ↑ RNA ↓ ↑ protein

Essay answer analysis

Makes Lemarckian evolution problematic

where the student is

where the student should be

Thursday, April 28, 2011
third option: conceptual assessments
third option: conceptual assessments

Essay

Bioliteracy and Teaching Efficacy: What Biologists Can Learn from Physicists

Michael W. Klymkowsky,* § Kathy Garvin-Doxas, † and Michael Zeilik‡

*Department of Molecular, Cellular & Developmental Biology and †Alliance for Learning, Technology & Society, University of Colorado, Boulder, Boulder, Colorado 80309-0347; and ‡Institute for Astrophysics, Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico 87131-1156
third option: conceptual assessments

Essay

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What “concepts” are we talking about?
What “concepts” are we talking about?

One effort: **The Biology Concept Framework**
What “concepts” are we talking about?

One effort: **The Biology Concept Framework**

18 major subject headers, 89 secondary headers (and a number of sub-sub headers).
What “concepts” are we talking about?

One effort: **The Biology Concept Framework**

18 major subject headers, 89 secondary headers (and a number of sub-sub headers).

“11-4. \( \Delta G^\circ \) is a thermodynamic property – an inherent characteristic of a reaction regardless of the starting conditions” – a physiochemical concept.
What “concepts” are we talking about?

One effort: **The Biology Concept Framework**

18 major subject headers, 89 secondary headers (and a number of sub-sub headers).

“11-4. \( \Delta G^o \) is a thermodynamic property – an inherent characteristic of a reaction regardless of the starting conditions” – a physiochemical concept.

“3-4. Many metabolic pathways are conserved across the evolutionary spectrum (e.g. glycolysis)” which posits an implicit understanding of metabolism, metabolic pathways, evolutionary mechanisms and relationships.

Thursday, April 28, 2011
Thinking about the Conceptual Foundations of the Biological Sciences

DOI: 10.1187/cbe.10-04-0061
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CBE—Life Sciences Education © 2010 American Society for Cell Biology.

M. W. Klymkowski

Molecular, Cellular and Developmental Biology and CU Teach, University of Colorado Boulder, Boulder CO 80309-0347
Thinking about the Conceptual Foundations of the Biological Sciences

M. W. Klymkowsky

Molecular, Cellular and Developmental Biology and CU Teach, University of Colorado Boulder, Boulder CO 80309-0347

Evolutionary thinking
- continuity [cell theory]
- stochastic processes [drift & mutation]
- selection → information generation

Molecular foundations
- thermodynamics: enthalpic & entropic factors
  - self-assembly & systems thinking
  - bond formation & catalysis
- affinity, specificity, and regulation (allostery)
  - the molecular level effects of mutation

Network behavior
- metabolic (non-equilibrium) networks
- adaptive, homeostatic, & evolving networks
  - e.g., molecular, embryological, neural, immune, ecological
Biological Concepts Instrument (BCI): A diagnostic tool for revealing student thinking

Michael W. Klymkowsky, Sonia M. Underwood, R. Kathleen Garvin-Doxas

(Submitted on 20 Dec 2010)

A key to effective teaching is an awareness and accurate understanding of the thinking and implicit assumptions that students bring to the subject to be learned. In the absence of extensive Socratic interactions with students, one strategy to assess student thinking involves the use of concept inventories (CIs). CIs are typically multiple-choice assessments, constructed based on research into student thinking and language, and designed to reveal the presence of common misconceptions and implicit assumptions pertaining to a particular facet of a subject. Here we describe the open-source Biological Concepts Instrument (BCI), a diagnostic, multiple-choice instrument designed to provide instructors with a preliminary map of a number of basic ideas in molecular level biology. We describe the strategy behind its design, the research upon which it is based, item construction, and its possible uses as a means to reveal and address persistent and often unrecognized conceptual obstacles.

Subjects: Other Quantitative Biology (q-bio.OT)
Cite as: arXiv:1012.4501v1 [q-bio.OT]

Submission history
From: Mike Klymkowsky [view email]
based on student thinking
based on student thinking

Recognizing Student Misconceptions through Ed's Tools and the Biology Concept Inventory

Michael W. Klymkowsky*, Kathy Garvin-Doxas
enables us to recognize difficult ideas
enables us to recognize difficult ideas

Article

Understanding Randomness and its Impact on Student Learning: Lessons Learned from Building the Biology Concept Inventory (BCI)

Kathy Garvin-Doxas* and Michael W. Klymkowsky†

*Center for Integrated Plasma Studies and †Molecular, Cellular, and Developmental Biology Department, University of Colorado, Boulder, CO 80309

Submitted August 23, 2007; Revised January 14, 2008; Accepted February 7, 2008

Monitoring Editor: Bruce Alberts

CBE—Life Sciences Education

Klymkowsky, 2011.ASBMB Today, Feb
enables us to recognize difficult ideas

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feature story

Why is evolution so hard to understand?

Realizing that function and biological meaning can arise from random processes may help people understand and accept evolution

BY MIKE KLYMKOWSKY

Klymkowsky, 2011.ASBMB Today, Feb
yet randomness rarely illustrated
yet randomness rarely illustrated

Q25: Imagine an ADP molecule inside a bacterial cell. Which best describes how it would manage to "find" an ATP synthase so that it could become an ATP molecule?
A. It would follow the hydrogen ion flow.
B. The ATP synthase would grab it.
C. Its electronegativity would attract it to the ATP synthase.
D. It would be actively pumped to the right area.
E. Random movements would bring it to the ATP synthase.
yet randomness rarely illustrated

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D. It would be actively pumped to the right area.
E. ✅ Random movements would bring it to the ATP synthase.

Teachers 58%
Q13: When we want to know whether a specific molecule will pass through a biological membrane, we need to consider ...
A. the specific types of lipids present in the membrane.
B. the degree to which the molecule is water soluble.
C. whether the molecule is actively repelled by the lipid layer.
D. whether the molecule is harmful to the cell.
Molecular level confusions

Q13: When we want to know whether a specific molecule will pass through a biological membrane, we need to consider ...
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C. whether the molecule is actively repelled by the lipid layer.
D. whether the molecule is harmful to the cell.
Why don’t oil and water mix?

A. Like dissolves like
B. Oil and water have different densities which causes them to separate.
C. There are no attractive forces between oil molecules and water molecules, and therefore the hydrogen bonds between water molecules would require too much energy to break.
D. The entropy of the system is higher in the unmixed state, because non-polar molecules cause water molecules to cluster around them.
E. Oil molecules repel water molecules
Why don’t oil and water mix?
Why don’t oil and water mix?

Like dissolves like (heuristic)
Why don’t oil and water mix?

Like dissolves like (heuristic)

Density (Naïve)

Gen Chem
Organic
Chem majors
Post-docs

Percent

A
B
C
D
E

Thursday, April 28, 2011
Why don’t oil and water mix?

- Like dissolves like (heuristic)
- H-bonds too strong. Didaskalogenic!
- Density (Naïve)
Why don’t oil and water mix?

Like dissolves like

H-bonds too strong. Didaskalogenic!

Density (Naïve)

Oil and water repel

Naïve/Didaskalogenic!

- Gen Chem
- Organic
- Chem majors
- Post-docs

Thursday, April 28, 2011
Why don’t oil and water mix?

- Like dissolves like (heuristic)
- H-bonds too strong. Didaskalogenic!
- Density (Naïve)
- Oil and water repel Naïve/Didaskalogenic!
- Entropy

Bar chart showing percent of responses from different groups (Gen Chem, Organic, Chem majors, Post-docs) for questions A to E.
Molecular level confusions
What makes DNA a good place to store information?

- The hydrogen bonds that hold it together are very stable and difficult to break.
- The bases always bind to their correct partner.
- The sequence of bases does not greatly influence the structure of the molecule.
- The overall shape of the molecule reflects the information stored in it.
What makes DNA a good place to store information?

The hydrogen bonds that hold it together are very stable and difficult to break. The bases always bind to their correct partner. The sequence of bases does not greatly influence the structure of the molecule. The overall shape of the molecule reflects the information stored in it.
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What makes DNA a good place to store information?

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In retrospect, the BCi is not a true concept inventory:
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1) typically CIs built with “Sequestered Problem Solving” (SPS), non-constructivist structure (memory based, non-transferrable) (Schwartz et al, 2009). BCi has a more PFL (preparation for future learning) structure based on transfer to new situations
In retrospect, the BCi is not a true concept inventory:

1) typically CIs built with “Sequestered Problem Solving” (SPS), non-constructivist structure (memory based, non-transferrable) (Schwartz et al, 2009). BCi has a more PFL (preparation for future learning) structure based on transfer to new situations.

2) to be robust, a CI must focus a number of independent items on a particular concept. Quite difficult in biology without “over-specification” - BCi is not “deep enough”.
In retrospect, the BCi is not a true concept inventory:

1) typically CIs built with “Sequestered Problem Solving” (SPS), non-constructivist structure (memory based, non-transferrable) (Schwartz et al, 2009). BCi has a more PFL (preparation for future learning) structure based on transfer to new situations

2) to be robust, a CI must focus a number of independent items on a particular concept. Quite difficult in biology without “over-specification” - BCi is not “deep enough”.

3) many CIs are based on assumption that “professionals” know the right answers! BCi questions are weird, and often confuse “experts”.

Thursday, April 28, 2011
The Null Ritual

What You Always Wanted to Know About Significance Testing but Were Afraid to Ask

Gerd Gigerenzer, Stefan Krauss, and Oliver Vitouch

No scientific worker has a fixed level of significance at which from year to year, and in all circumstances, he rejects hypotheses; he rather gives his mind to each particular case in the light of his evidence and his ideas. (Ronald A. Fisher, 1956, p. 42)

It is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail. (A. H. Maslow, 1966, pp. 15–16)
Figure 1. The Amount of Delusions About the Meaning of "$p = .01$".

Note. The percentage refer to the participants in each group who endorsed one or more of the six false statements (based on Haller & Krauss, 2002).

Gerd Gigerenzer, Stefan Krauss, and Oliver Vitouch
BCi questions as useful diagnostics: particular when students are asked to explain why wrong responses are wrong (and you listen to their answers).
time line

education

job

today

Development and Assessment of Chemistry, Life, the Universe & Everything (CLUE)

what is fundamental?

what do students know?

Development of SocraticGraphs / BeSocratic

collaboration with Melanie Cooper, Clemson

Thursday, April 28, 2011
Trujillo & Klymkowsky, *Using graph-based assessments within Socratic tutorials to reveal and refine students’ analytical thinking about molecular networks.* BAMED submitted.
Caleb Trujillo

Can junior/senior level molecular biology students transfer their understanding to the analysis a simple molecular system?
A simple task: generate a graph that displays the behavior of the system.

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Why graphs?

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Why graphs?

Trujillo & Klymkowsky, *Using graph-based assessments within Socratic tutorials to reveal and refine students’ analytical thinking about molecular networks.* BAMED submitted.
16 assumptions: grouped into four major areas:
16 assumptions: grouped into four major areas:

i) the effects of an activator/repressor on the rate of transcription initiation;
16 assumptions: grouped into four major areas:

i) the effects of an activator/repressor on the rate of transcription initiation;

ii) the time required for RNA and polypeptide synthesis (transcription and translation);
16 assumptions: grouped into four major areas:

i) the effects of an activator/repressor on the rate of transcription initiation;

ii) the time required for RNA and polypeptide synthesis (transcription and translation);

iii) the half lives of the RNA and polypeptides produced;
16 assumptions: grouped into four major areas:

i) the effects of an activator/repressor on the rate of transcription initiation;

ii) the time required for RNA and polypeptide synthesis (transcription and translation);

iii) the half lives of the RNA and polypeptides produced;

iv) the nature of the interactions between proteins, and between proteins and other molecules.
~85% failed to indicate delay between gene activation and polypeptide appearance.
~85% failed to indicate delay between gene activation and polypeptide appearance.

~50% of students explicitly stated only 1 assumption; 30% stated two
~12% stated more than two.
~85% failed to indicate delay between gene activation and polypeptide appearance.

~50% of students explicitly stated only 1 assumption; 30% stated two
~12% stated more than two.

~80% of assumptions involved the nature of the negative feedback interaction.
~85% failed to indicate delay between gene activation and polypeptide appearance.

~50% of students explicitly stated only 1 assumption; 30% stated two
~12% stated more than two.

~80% of assumptions involved the nature of the negative feedback interaction.

~78% of graphic responses implied B induced the degradation of A; only ~13% stated this assumption explicitly.
I’ll pause for a moment so you can let this information sink in.
OrganicPad: inspiration for SocraticGraphs

The arrow always starts on an electron source (a nucleophile) and ends on an electron sink (an electrophile).

Put your finger on the electron source and trace the path of the electrons from the electron source to the electron sink.
Far Transfer Success Rate (%)

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied</td>
<td>18</td>
<td>53</td>
</tr>
<tr>
<td>Paper, draw</td>
<td>18</td>
<td>35</td>
</tr>
<tr>
<td>Paper, read</td>
<td>18</td>
<td>70</td>
</tr>
</tbody>
</table>

Control (Historical Data)
BeSocratic/SocraticGraphs

A free-form graphical representation system designed to capture, recognize, and respond to student inputs and common mistakes using “prods and perturbations”.
BeSocratic/SocraticGraphs

A free-form graphical representation system designed to capture, recognize, and respond to student inputs and common mistakes using “prods and perturbations”.

Draw Maxwell-Boltzmann distribution
BeSocratic/SocraticGraphs

A free-form graphical representation system designed to capture, recognize, **and respond** to student inputs and common mistakes using “prods and perturbations”.

Draw Maxwell-Boltzmann distribution
BeSocratic/SocraticGraphs

A free-form graphical representation system designed to capture, recognize, and respond to student inputs and common mistakes using “prods and perturbations”.

Draw Maxwell-Boltzmann distribution
Let us try and predict how our simple system behaves.

At time 0, the concentration of A polypeptide is 0. S is added at time \( t = 2 \) and remains in the system thereafter. Expression of the gene is dependent upon the presence of S. The concentration of \([A]\) reaches its maximum at time \( t = 12\).

Graph the concentration of A \([A]\) as a function of time.
time line

education

job

\{ professor \} with Melanie Cooper, Clemson

Development and Assessment of Chemistry, Life, the Universe & Everything (CLUE)

Development of SocraticGraphs / BeSocratic

Thursday, April 28, 2011
Chemistry has an image problem
Chemistry has an image problem

“Chemistry is the subject that at least 6 out of every 6.0225 Americans insist they “flunked in high school.”

If you listen to chemists, it is biologists’ fault that students believe that **breaking bonds** releases energy, but

Based on ed’s tools question analyses by Cooper et al.
If you listen to chemists, it is biologists’ fault that students believe that breaking bonds releases energy, but

yet...

<table>
<thead>
<tr>
<th>Level</th>
<th>% with misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen Chem (77)</td>
<td>50</td>
</tr>
<tr>
<td>Organic (172)</td>
<td>65</td>
</tr>
<tr>
<td>Inorganic (13)</td>
<td>54</td>
</tr>
<tr>
<td>Analytical (35)</td>
<td>51</td>
</tr>
<tr>
<td>P Chem (16)</td>
<td>56</td>
</tr>
<tr>
<td>Graduate students (21)</td>
<td>68</td>
</tr>
<tr>
<td>Post Docs (25)</td>
<td>68</td>
</tr>
</tbody>
</table>

Based on ed’s tools question analyses by Cooper et al.
Evidence that current textbook design and approaches to teaching actually are counterproductive

Evidence that current textbook design and approaches to teaching actually are counterproductive

For both CLUE & Biofundamentals
For both CLUE & Biofundamentals

• Is there an optimum order of topics?
For both CLUE & Biofundamentals

- Is there an optimum order of topics?
- What prior knowledge do students bring?
For both CLUE & Biofundamentals

• Is there an optimum order of topics?
• What prior knowledge do students bring?
• how does it interact (constructive/destructive interference) with new knowledge?
For both CLUE & Biofundamentals

- Is there an optimum order of topics?
- What prior knowledge do students bring?
- how does it interact (constructive/destructive interference) with new knowledge?
- What concepts are important / difficult?
For both CLUE & Biofundamentals

- Is there an optimum order of topics?
- What prior knowledge do students bring?
- How does it interact (constructive/destructive interference) with new knowledge?
- What concepts are important / difficult?
- What does it look like when students understand these concepts?
For both CLUE & Biofundamentals

• Is there an optimum order of topics?
• What prior knowledge do students bring?
• How does it interact (constructive/destructive interference) with new knowledge?
• What concepts are important / difficult?
• What does it look like when students understand these concepts?
Learning Approach
Learning Approach

• Elicit student thinking about concepts
Learning Approach

• Elicit student thinking about concepts
• Make students explicitly reflect about their answers and observations; ask them to explain.
Learning Approach

• Elicit student thinking about concepts
• Make students explicitly reflect about their answers and observations; ask them to explain.
• Spiral approach
Learning Approach

• Elicit student thinking about concepts
• Make students explicitly reflect about their answers and observations; ask them to explain.
• Spiral approach
• Repeated, formative assessment
Learning Approach

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• Make students explicitly reflect about their answers and observations; ask them to explain.
• Spiral approach
• Repeated, formative assessment

Data coming in: oil and water mix?

Like dissolves like (heuristic)

H-bonds too strong. Didaskalogenic!

Oil and water repel Naïve/Didaskalogenic!

Density (Naïve)

Entropy
Data coming in: oil and water mix?

Like dissolves like (heuristic)

CLUE students →

H-bonds too strong. Didaskalogenic!

Oil and water repel Naïve/Didaskalogenic!

Density (Naïve)

Entropy

- Gen Chem
- Organic
- Chem majors
- Post-docs

A | B | C | D | E
---|---|---|---|---
Gen Chem | Organic | Chem majors | Post-docs

Thursday, April 28, 2011
More information:

Google: Biofundamentals, Bioliteracy, BeSocratic.clemson or colorado.edu
“We’d now like to open the floor to shorter speeches disguised as questions.”