Biofundamentals (and CLUE): a discussion about scientists teaching science

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University of Colorado Boulder, Boulder, CO. 80309

Apologize for speaking in English

- do not hesitate to ask if I need to be clearer

Acknowledging collaborators

- Kathy Garvin-Doxas and Ed Svirsky: Eds Tools and the BCI
- Valerie Otero, Julie Andrews, Jeff Winters - CU Teach
- Bilge Birsoy - CRIPSR CURE course
- Ernst Hafen, Katje Kohler and Annie Champagne-Queloz - ETH, Zurich
- Delmar Larsen - LibreText collaborative (open education resources)

Melanie Cooper & her group (Clemson/Michigan State University)

- Sonia Underwood, Ryan Stowe, Olivia Crandell and others (analysis of curricular effects)
- CLUE, OCLUE, CLUE+ and biofundamentals web to text transition
- Sam Bryfcynski - beSocratic)
- MSU students

BeSocratic

people I need to thank

Topics I will consider:

- How do we redesign course materials to enhance engagement and effectiveness
- Goal is using ideas rather than recognizing them

Where to start

- Understand what students know and think
    - concept tests (BCI)
    - formative assessments (beSocratic)

Features of concept tests …

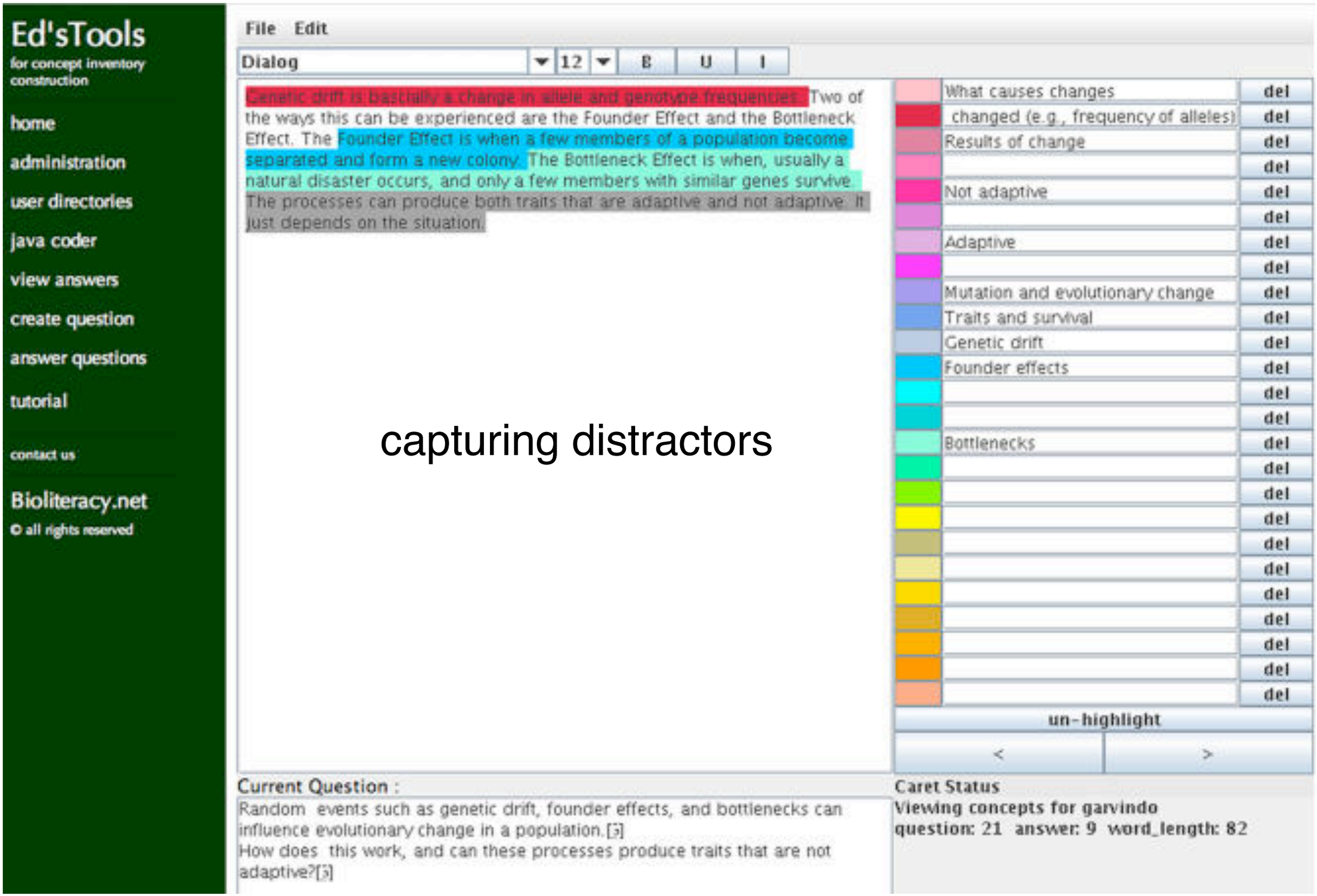
- Questions are **conceptual** (not factual recall)
- **Distractors** (incorrect response choices) are derived from student thinking, attractive to students.

"… Rebello & Zollman (2004) examined students' open-ended responses to FCI questions, their analyses revealed aspects of student thinking not found in the original FCI distractors. **Based on student responses, these authors generated new distractors to replace the original ones**, resulting in a **decrease in the frequency of correct answers**, suggesting that the original FCI distractors did not fully capture aspects of students' thinking.

Lessons to be taken from their observations:

1. difficult for instructors to accurately predict what students are thinking and
2. different groups of students may hold different ideas.
3. both influence concept test results as measures of learning.

- Klymkowsky & Garvin-Doxas (2020), Concept Tests, submitted.



capturing distractors

concept tests

What makes DNA a good place to store information?

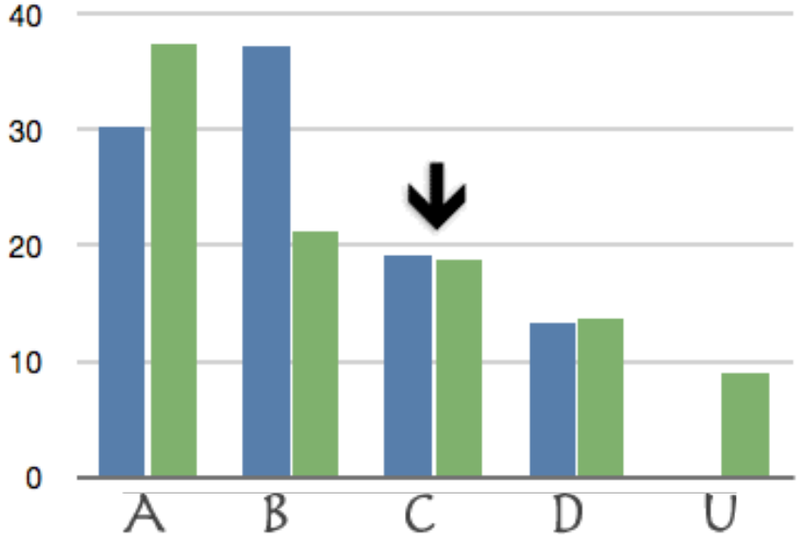
The hydrogen bonds that hold it together are very stable and difficult to break.

The bases always bind to their correct partner.

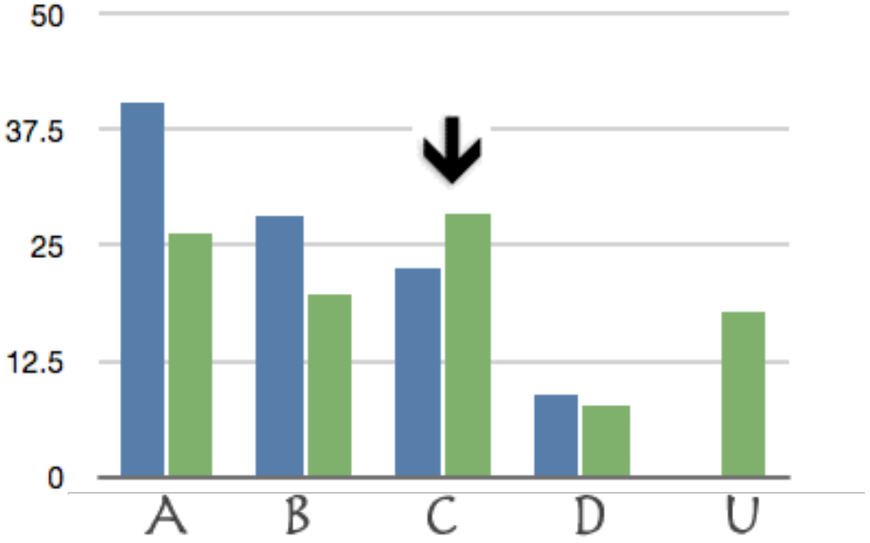
The sequence of bases does not greatly influence the structure of the molecule.

The overall shape of the molecule reflects the information stored in it.

- teachers 29%



intro



advanced

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†

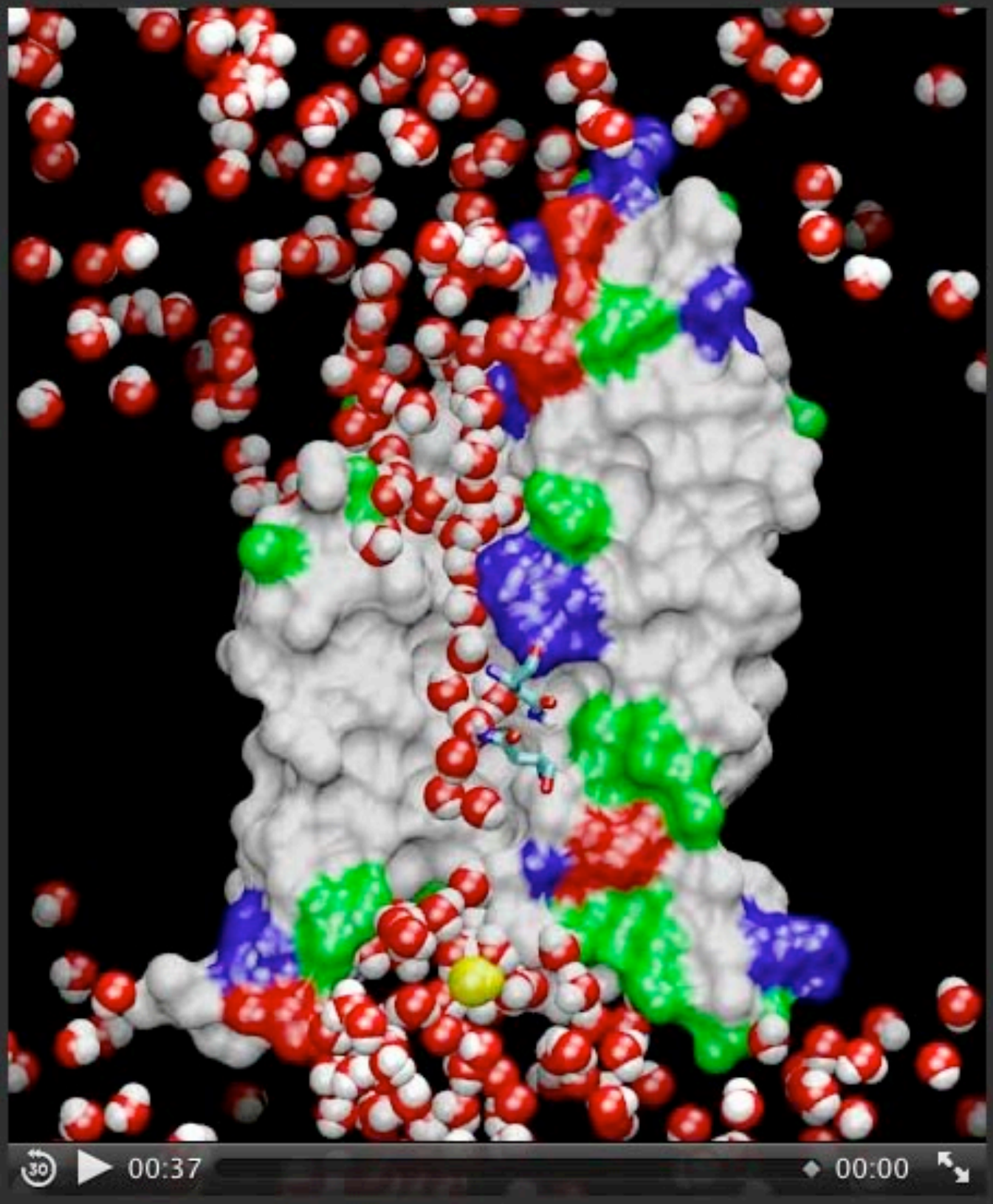
*Center for Integrated Plasma Studies and †Molecular, Cellular, and Developmental Biology Department, University of Colorado, Boulder, CO 80309

Submitted August 23, 2007; Revised January 14, 2008; Accepted February 7, 2008
Monitoring Editor: Bruce Alberts

CBE—Life Sciences Education
Vol. 7, 227–233, Summer 2008

Address issues head on and repeatedly to illustrate how stochastic processes"work"

stochasticity



http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2003/chemanim1.mpg

BeSocratic : revealing student thinking

A Short History of the Use of Technology To Model and Analyze Student Data for Teaching and Research

Melanie M. Cooper,[*,1] Sonia M. Underwood,[1] Sam P. Bryfczynski,[1] and Michael W. Klymkowsky[2]

Sketching the Invisible to Predict the Visible: From Drawing to Modeling in Chemistry

Melanie M. Cooper,[a] Mike Stieff,[b] Dane DeSutter[c]

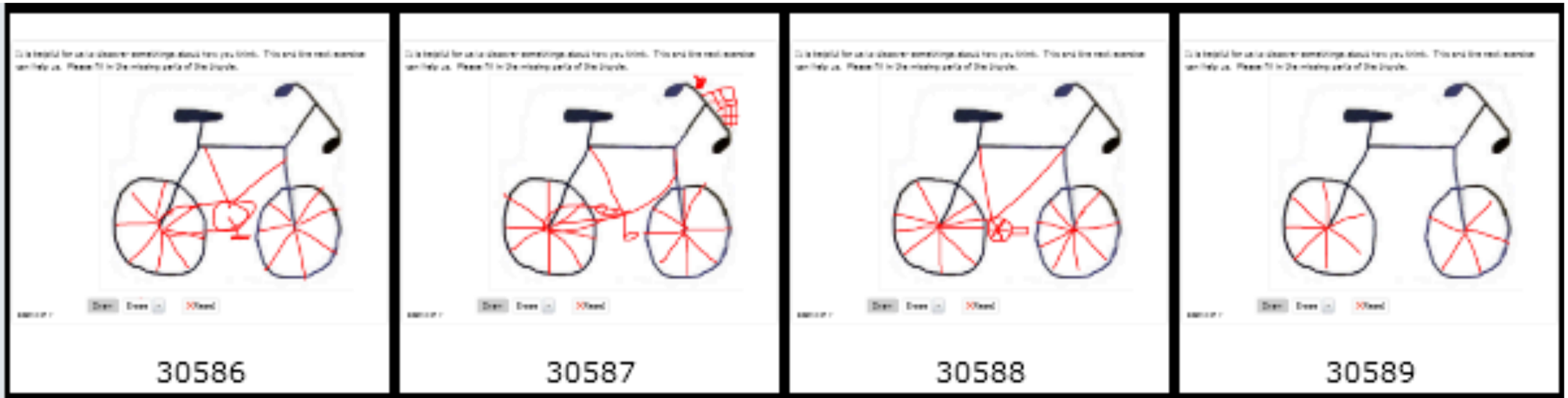
revealing student thinking

It is helpful for us to discover somethings about how you think. This and the next exercise can help us. Please fill in the missing parts of the bicycle.

Draw | Erase | Reset

It is helpful for us to discover somethings about how you think. This and the next exercise can help us. Please fill in the missing parts of the bicycle.

Draw Erase Reset


30586
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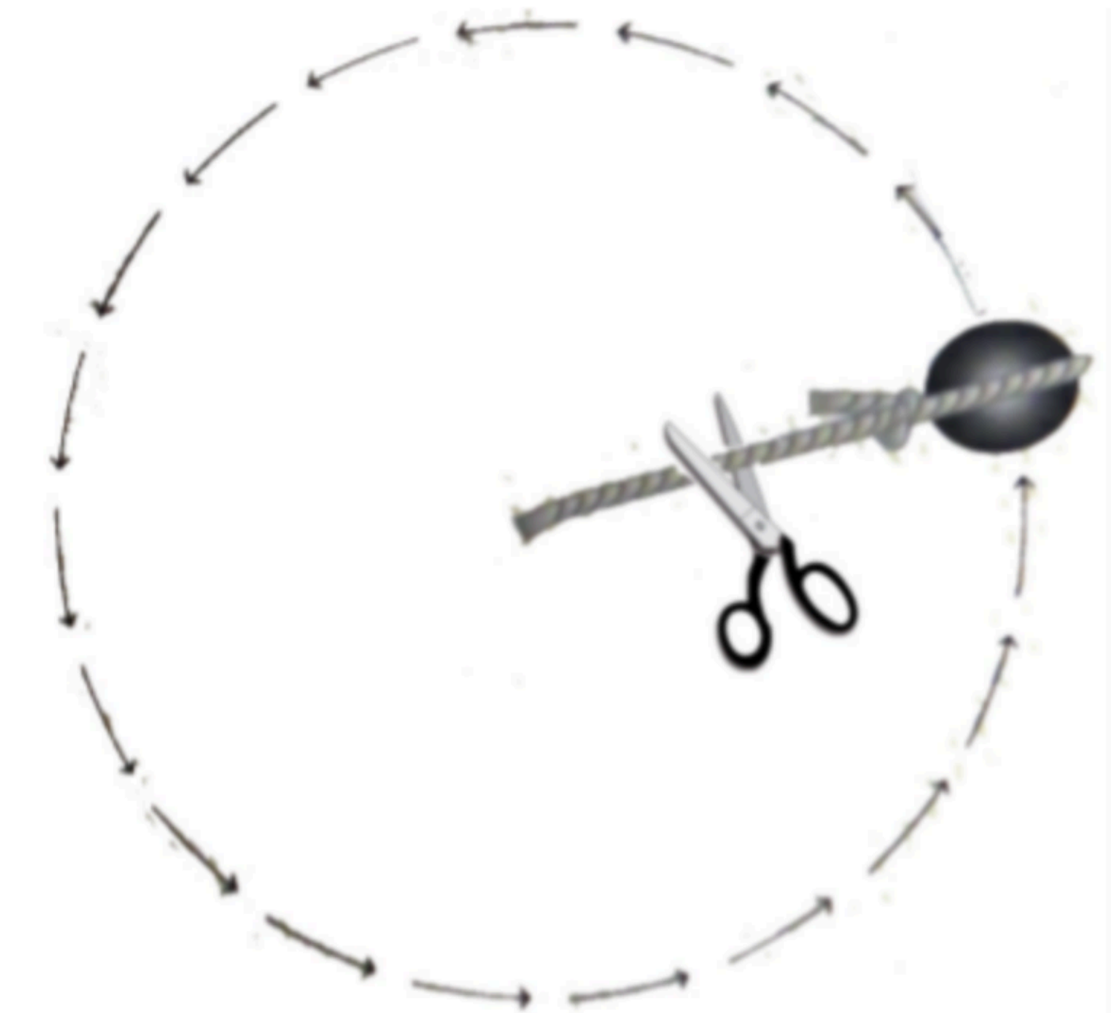
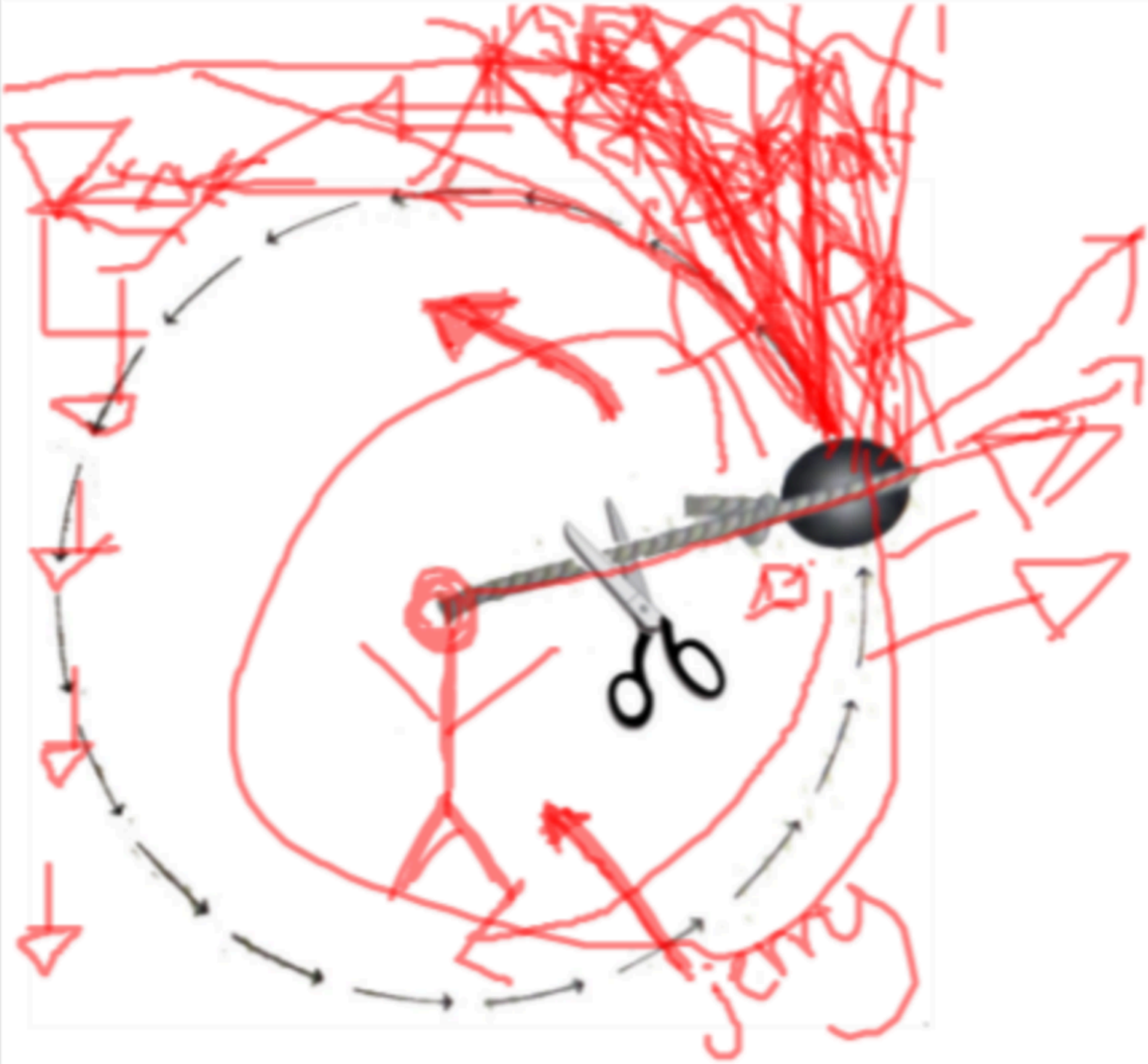
The diagram shows a rock attached by a rope to a person (at the center) who is spinning it around their head. Draw how you think the the rock will move if the person lets go of the rope



Draw | Erase | Reset

What ideas did you use in your answer?

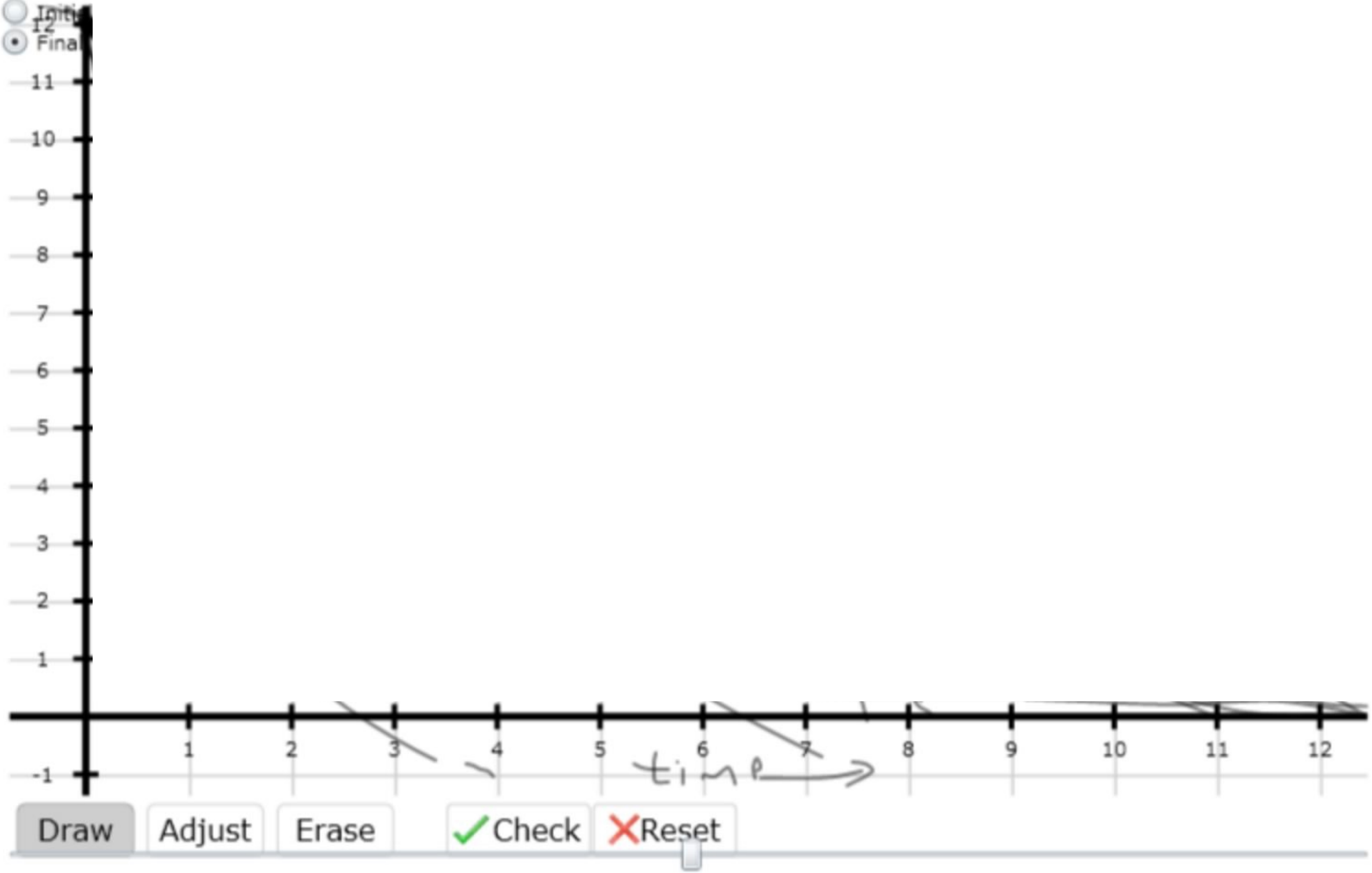
The diagram shows a rock attached by a rope to a person (at the center) who is spinning it around their head. Draw how you think the the rock will move if the person lets go of the rope



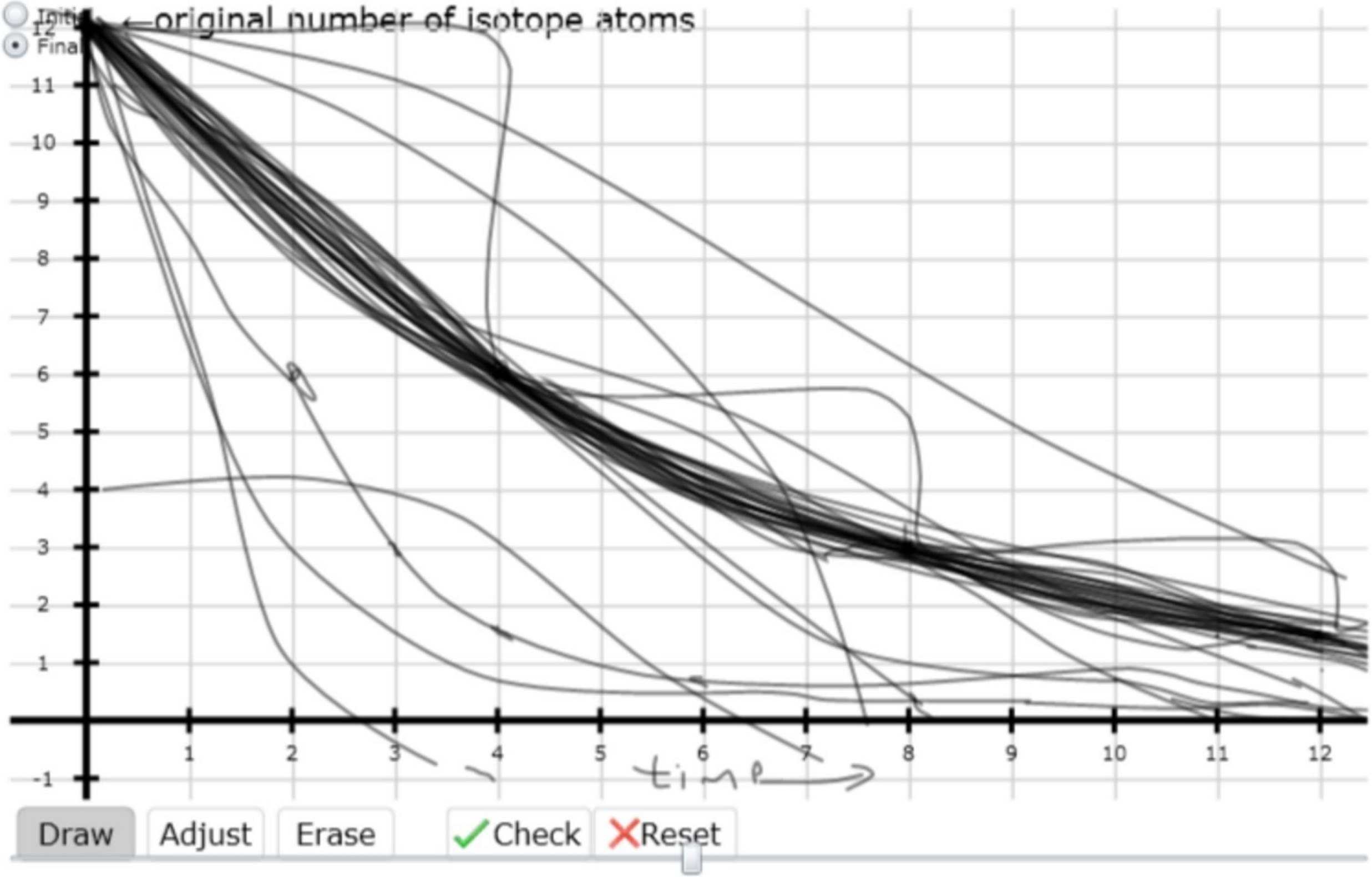
Draw | Erase | Reset

What ideas did you use in your answer?

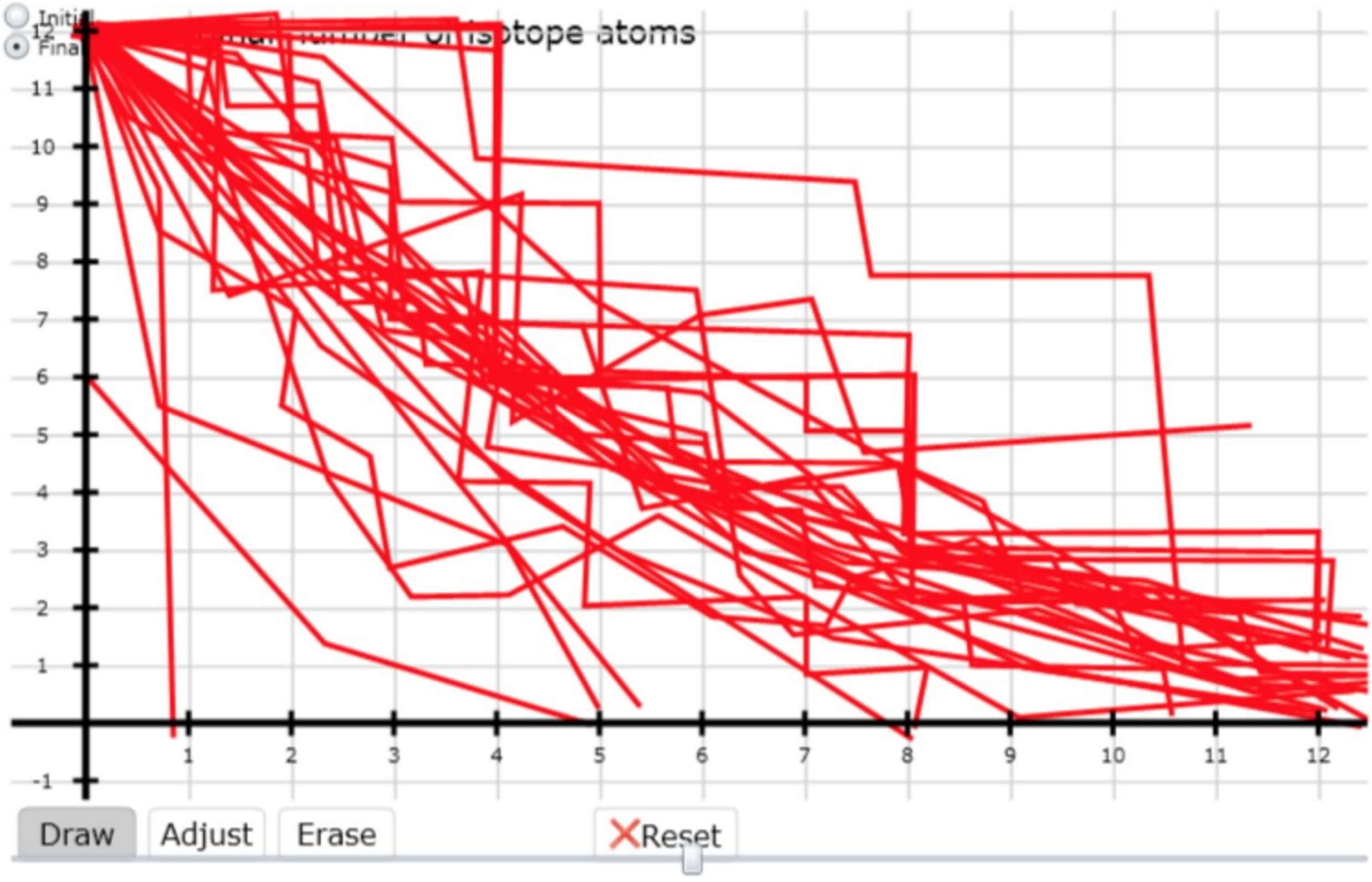
2.2: Now draw the half-life relationship graphically. The half-life of this isotope is 4 time units and you begin with 12,000,000,000 isotope atoms



2.2: Now draw the half-life relationship graphically. The half-life of this isotope is 4 time units and you begin with 12,000,000,000 isotope atoms



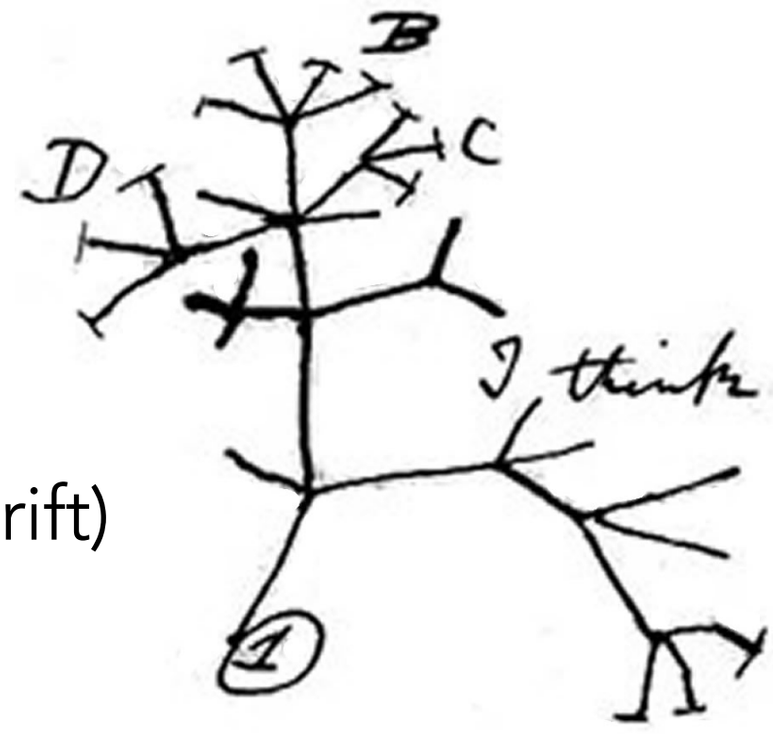
2.3: Now consider how your graph will change if you started with only 12 atoms? Draw a plausible graph of the behavior of 12 isotope atoms.



Origins of biofundamentals

- Existing MCDB course
  - no discussion of (social) evolutionary mechanisms
  - stochastic processes
  - Lack of recurrent themes
- built first as interactive web site
- transformed into an open source book,

Focus of biofundamentals



- **Evolutionary processes**
  - continuity (cell theory)
  - stochastic processes (mutation and drift)
  - selection (information generation)
- **Molecular foundations**
  - Thermodynamics: enthalpic and entropic factors
  - self-assembly and systems thinking
  - bond formation and catalysis
  - affinity, specificity, and regulation (allostery)
- **Network behaviors**
  - metabolic (non-equilibrium) coupled reaction networks
  - adaptive, homeostatic, responsive & evolving networks

CBE Life Sci Educ. 2010 Winter;9(4):405-7. doi: 10.1187/cbe.10-04-0061.

Thinking about the conceptual foundations of the biological sciences.

Klymkowsky MW[1].

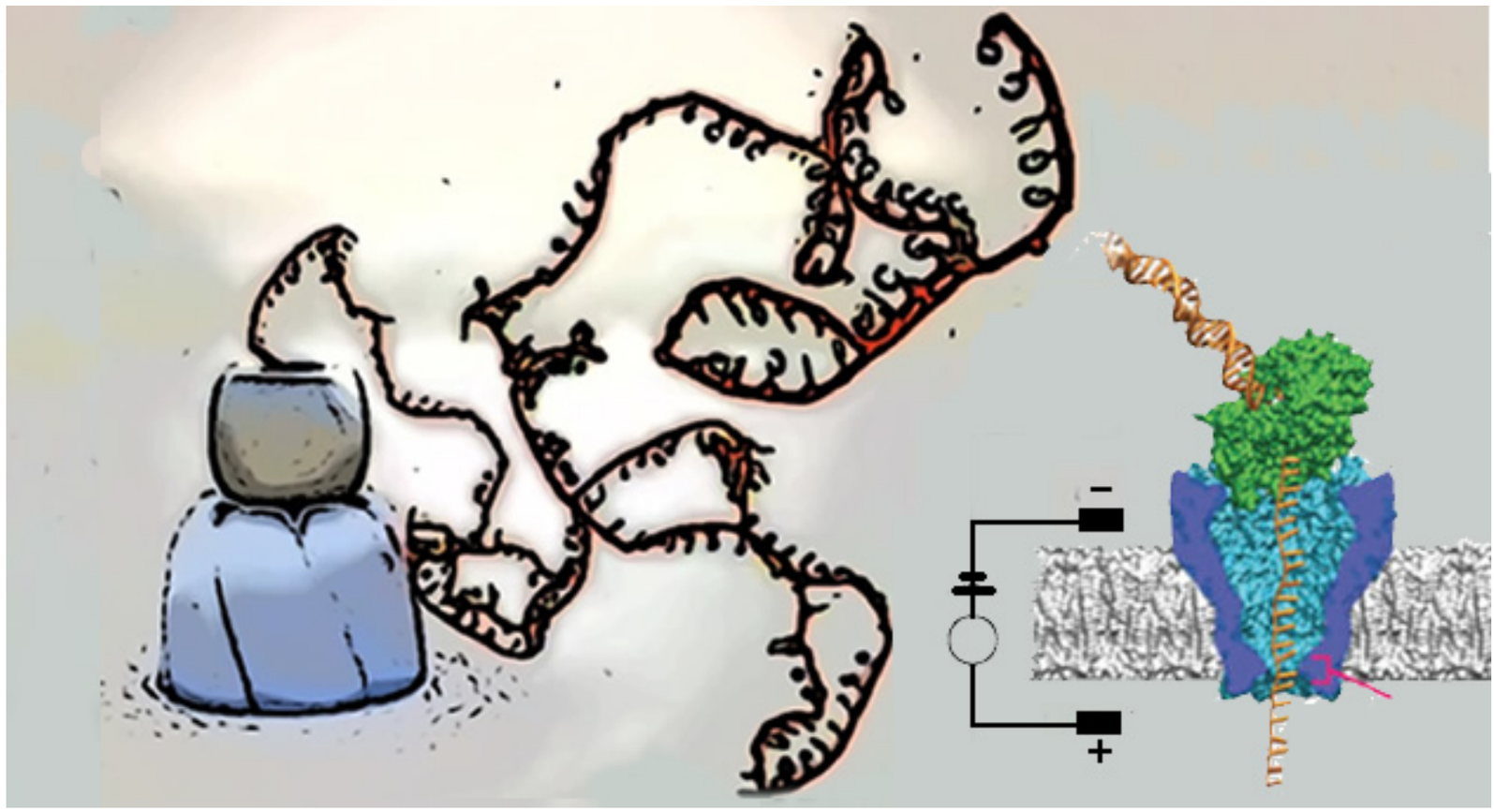
The Cell as a Collection of Protein Machines: Preparing the Next Generation of Molecular Biologists

Overview

Bruce Alberts
President, National Academy of Sciences

common (bio)molecular machines:

spears and injectors
molecular importers (nuclear pores)
walking+dragging (motors)
propellers and oars (cilia + flagella)
DNA detanglers (topoisomerases)
clamps
chaperones + unfolders
recyclers (proteosome) ...

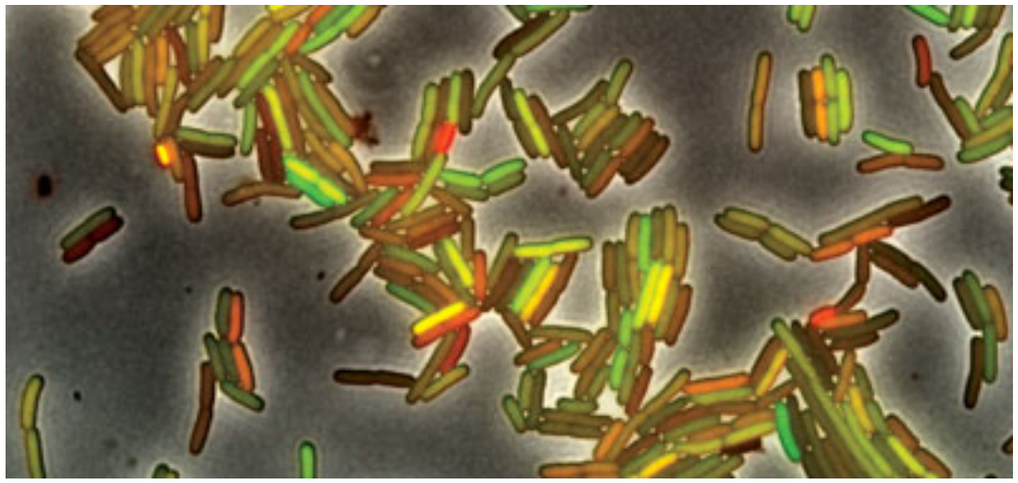


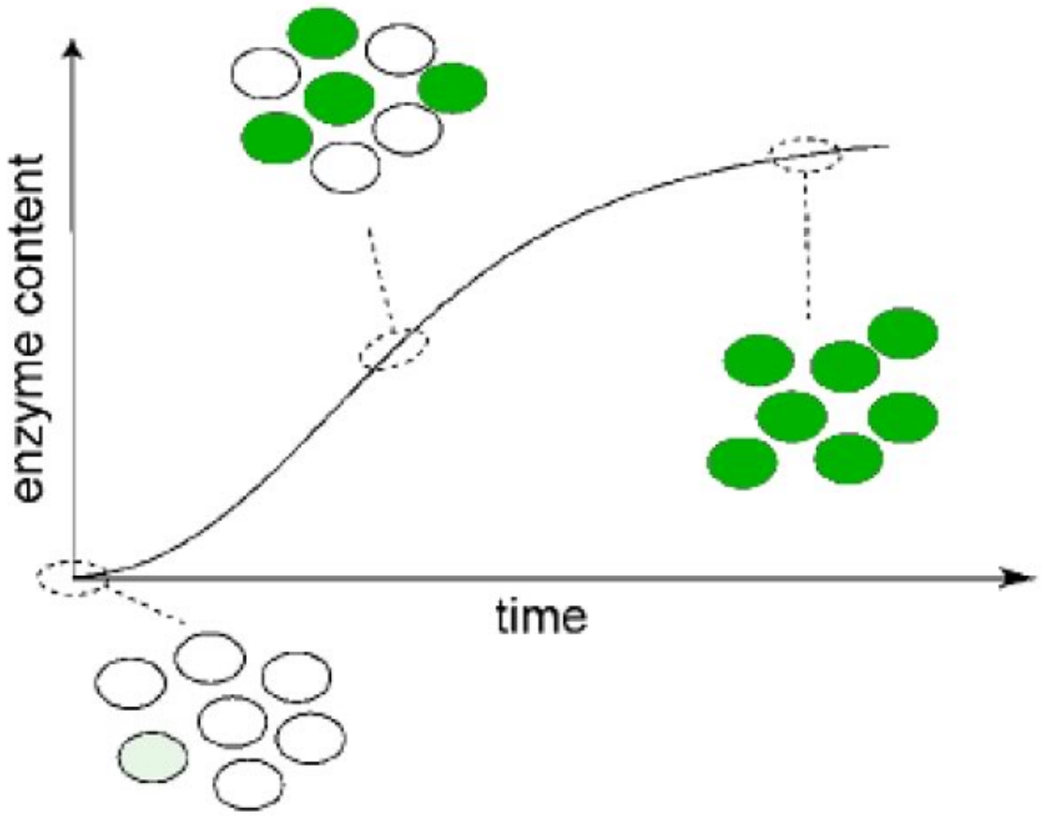
engineering more effective courses: biofundamentals

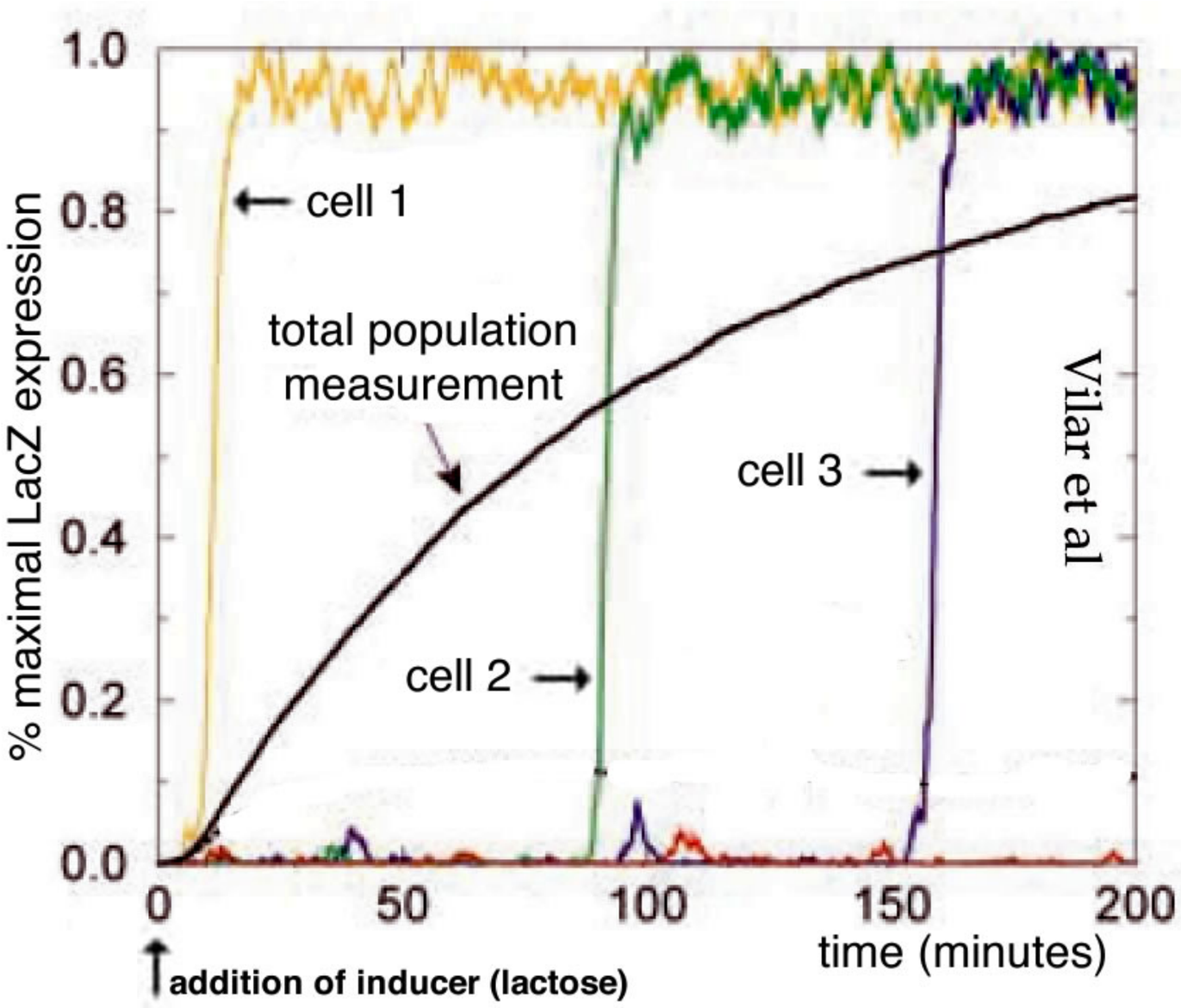
- biological systems are not intelligently designed.

Rube Goldberg

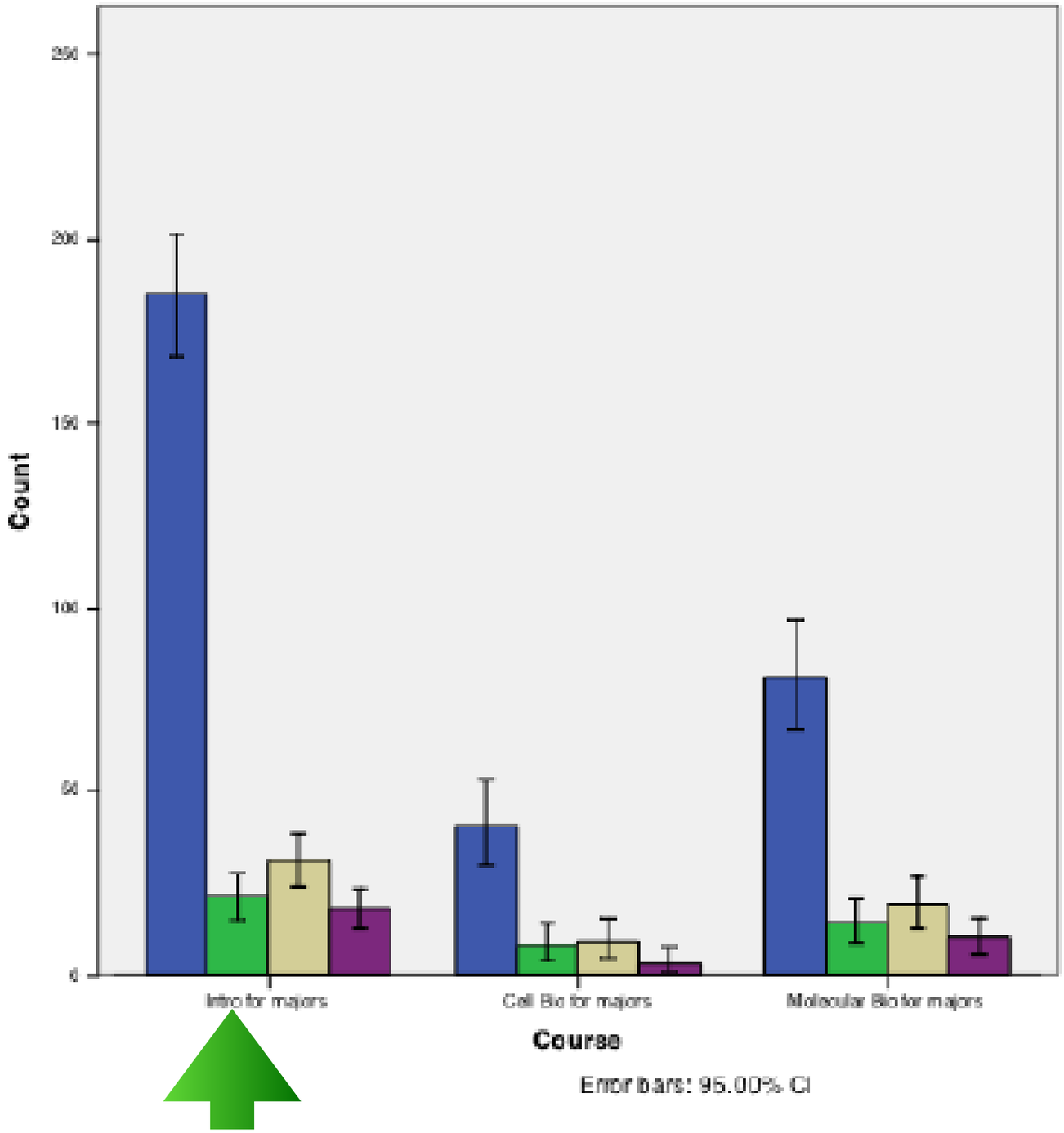
- biological systems are inherently stochastic.







- students often do not "get" stochastics systems.

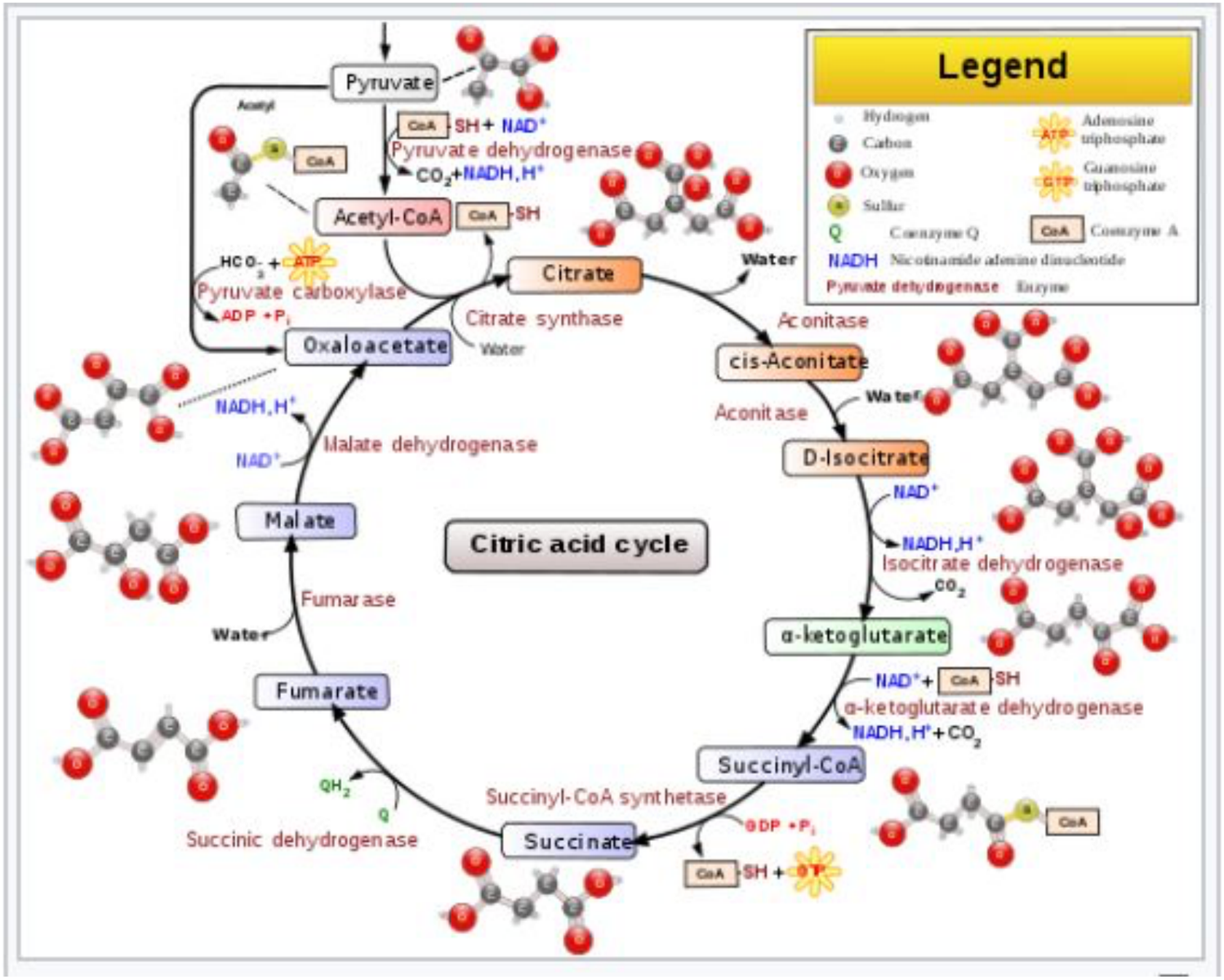


Once two molecules bind to one another, how could they come back apart again?

a) A chemical reaction must change the structure of one of the molecules
b) Collisions with other molecules could knock them apart
c) The complex will need to be degraded
d) They would have to bind to yet another molecule

- biological systems are based on systems of coupled chemical reactions.

- at the conceptual level, what is important is the **ubiquity of coupled reaction**, rather than specific reactions



continues generation after generation, with no force pushing the frequency back to its initial state
because the population has no "genetic memory" of its state many generations ago.

Each generation is an independent event. The final resul
frequency is that the population eventually drifts to p
change is possible; the population has become homozyg

A different population, isolated from the first, also underg
become homozygous for allele "A", whereas the first pop
"a".

As time goes on, isolated populations diverge from each
variation originally present within populations now appe
(Suzuki et al., 1989. An Introduction to Genetic Analysis

These non-selective, sampling-based effects are one rea
whether a particular trait is adaptive or not. It really deper

The end result of founder effects, bottlenecks, and genet
represented in a population by chance.

Questions to answer

1. Consider the various ways that the i
bottleneck might differ from those th
can you identify?
2. Based on the Java Genetic Drift appl
from 5% to 100% of the population
3. How does selection act to limit the e
4. Is it possible for a genetic bottleneck
frequency of a deleterious trait than
the bottleneck? How does this occur
5. Assume that all members of a population that pass through a bottleneck have a deleterious trait; can the population survive and, if so, how would selection act on the population after the bottleneck?

Questions to ponder

- What limits the "size" of the founder effect or a bottleneck effect?
- Does passing through a bottleneck improve or hamper a population's chances for evolutionary success (that is, avoiding extinction)?

Based on the Java Ge[...] Sort by Oldest

Share This Highlight Via Twitter Facebook Email

student 1 Posted 2 months ago
Based on the Java Genetic Drift applet, it IS possible for an allele to go from 5% to 100% of the population simply by genetic drift. The graph showed this.
Respond Share

student 2 Posted 2 months ago
I agree, especially in smaller populations
Respond Share

student 3 Posted 2 months ago
I also agree, no matter how unlikely it may be. However, within smaller populations, if the trait is truly advantageous it is more likely to be seen.
Respond Share

student 4 Posted 2 months ago
Even though this is possible, would it really happen in a population? If so, can anyone think of an example to help me understand?
Respond Share

student 5 Posted 2 months ago
Yes. but that happens under low possibility.
Respond Share

http://virtuallaboratory.colorado.edu/Biofundamentals/lectureNotes/Topic1E_Evo.htm

Chapters

1: Understanding (biological) science & thinking scientifically

2: Life and its origins

3: Evolutionary mechanisms and the diversity of life

4: Social evolution and sexual selection

5: Molecular interactions, thermodynamics & reaction coupling

6: Membrane boundaries and capturing energy

7: The molecular nature of the heredity material

8: Peptide bonds, polypeptides, proteins, and molecular machines

9: Organizing and expressing genes in regulatory networks

10: Cellular topology and intercellular signaling

Available through LibreText

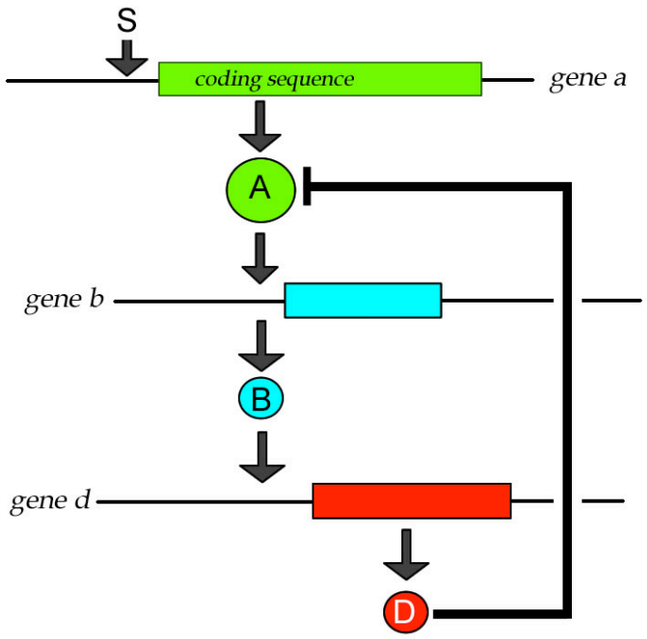
(or from us)

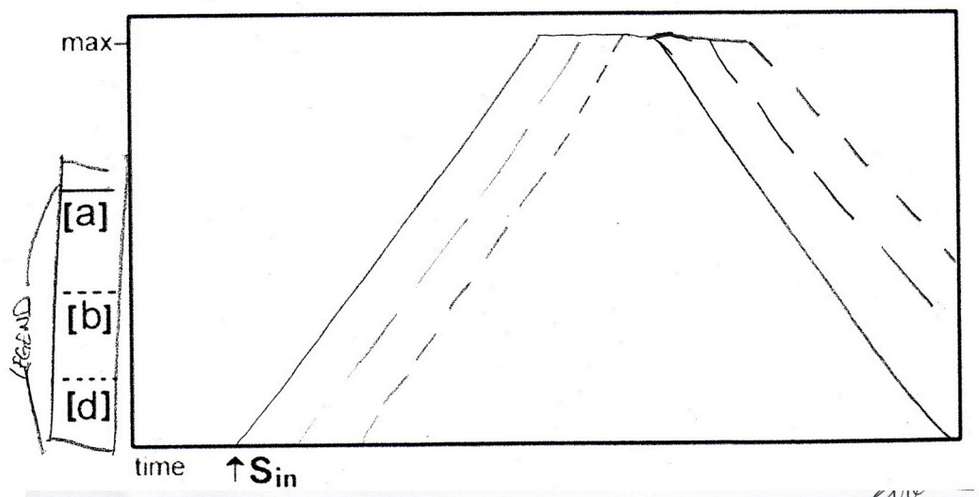
Questions to answer:
Why is a non-linear response to a stimulus important in biological systems? How is it achieved?

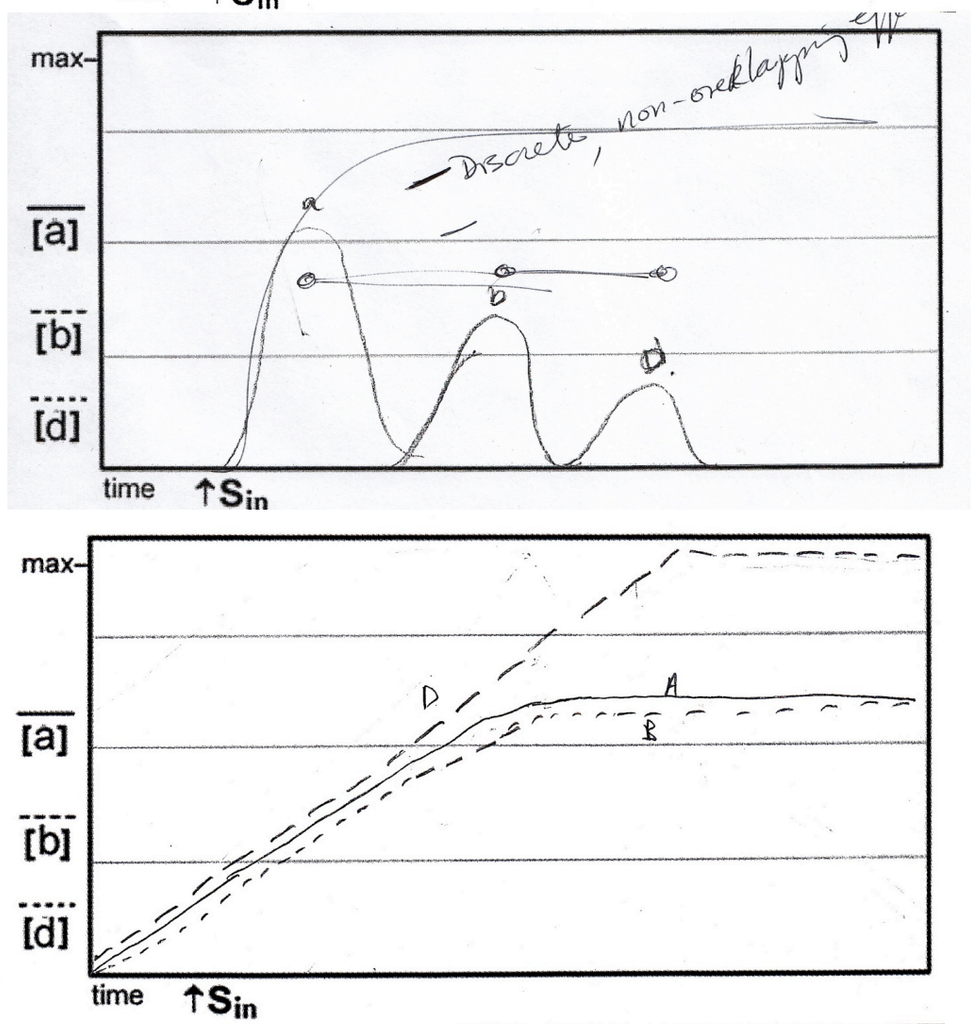
Question to ponder:
How it might it impact the social behavior of slime molds if the percentage of spore cells were 1% rather than 80%?

1. If the coding regions of two genes overlapped,
❏ A. it is likely that the expression of one would not effect the expression of the other
❏ B. It is likely that both would be expressed at high levels at the same time
❏ C. a single mutation could change the primary sequence of both polypeptides.
❏ D. they would share a common regulatory sequence ❏ no idea
___ is wrong because (you might want to use a drawing to make your argument clear).

Graphic problems: generate a graph that displays the behavior of the system; state explicitly the assumption you used.







Students' thinking revealed

Using Graph-based Assessments Within Socratic Tutorials to Reveal and Refine Students' Analytical Thinking About Molecular Networks[S]*

Received for publication, August 6, 2011, and in revised form, November 10, 2011

Caleb Trujillo‡, Melanie M. Cooper§, and Michael W. Klymkowsky‡,¶

revealing student thinking

CLUE

CHEMISTRY, LIFE, THE UNIVERSE & EVERYTHING

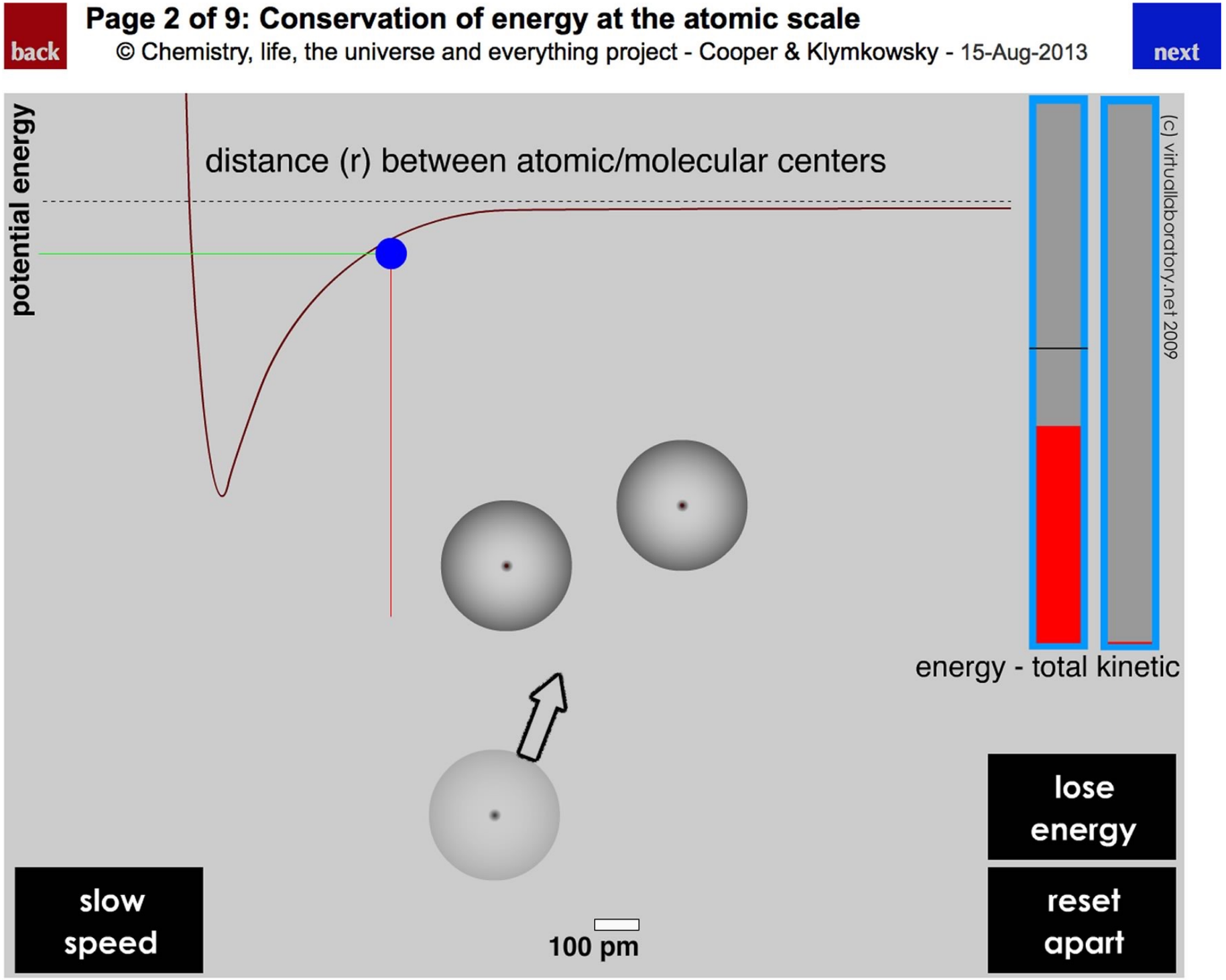
CLUE

ORGANIC CHEMISTRY

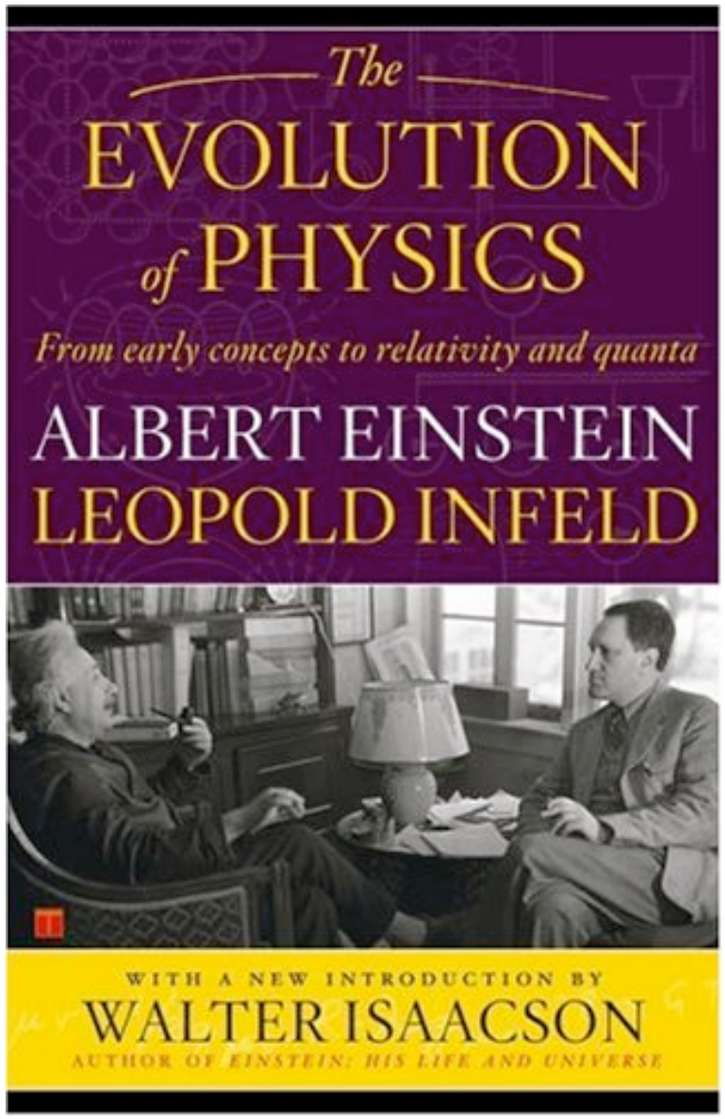
LIFE, THE UNIVERSE & EVERYTHING

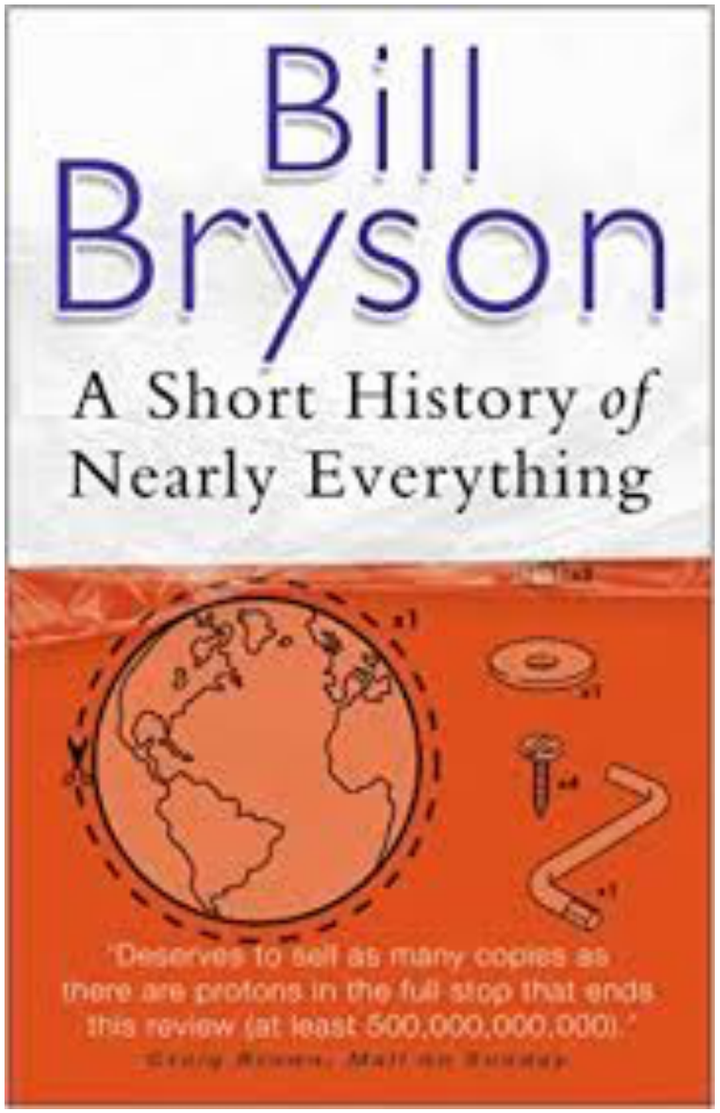
Catalyst for CLUE

conversations at Chemistry Education Gordon Conference on energetics of bond breaking & bond formation

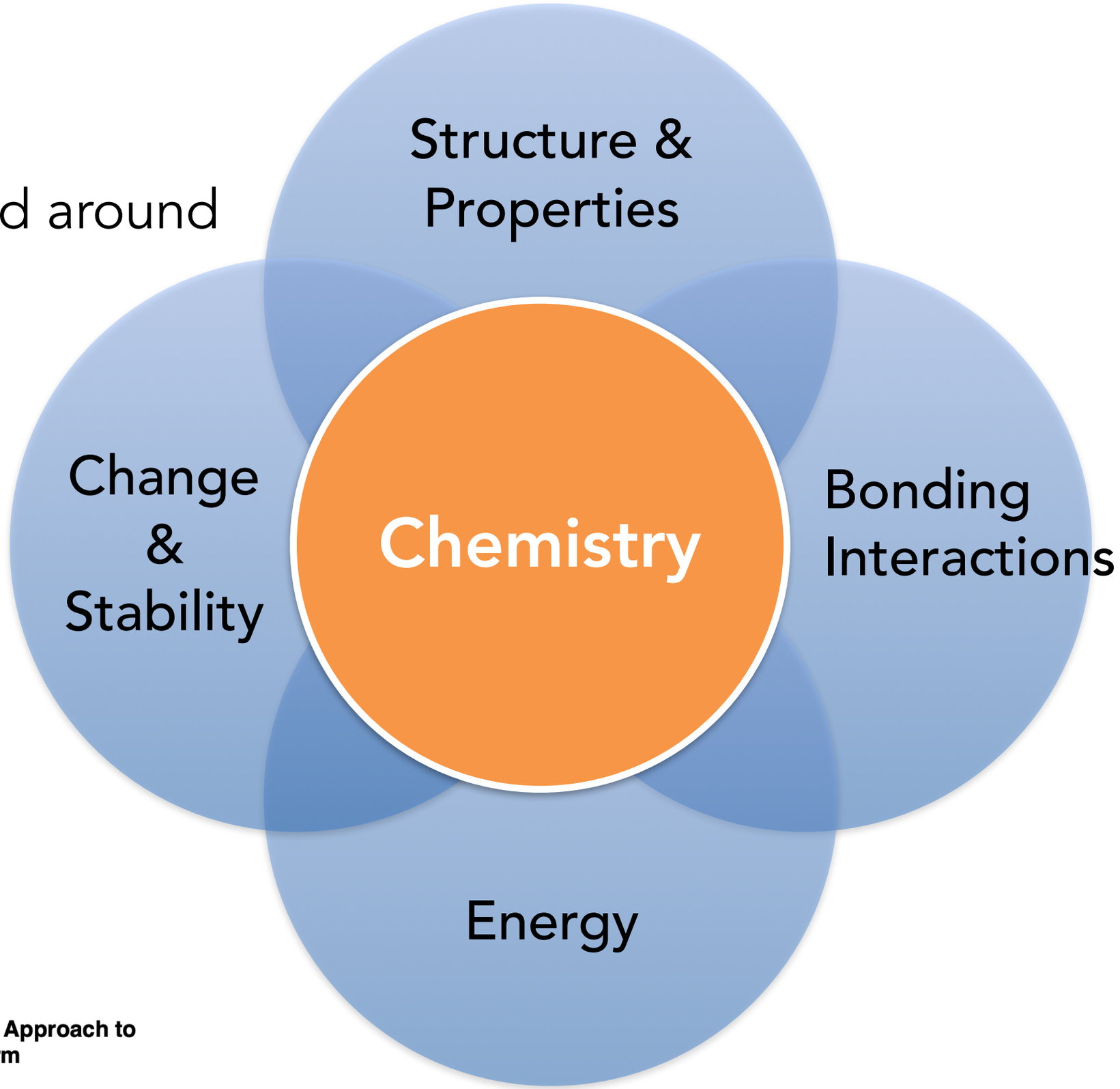


Writing style (minimal figures) – narrative framework for materials presented – practice through beSocratic and in class activities





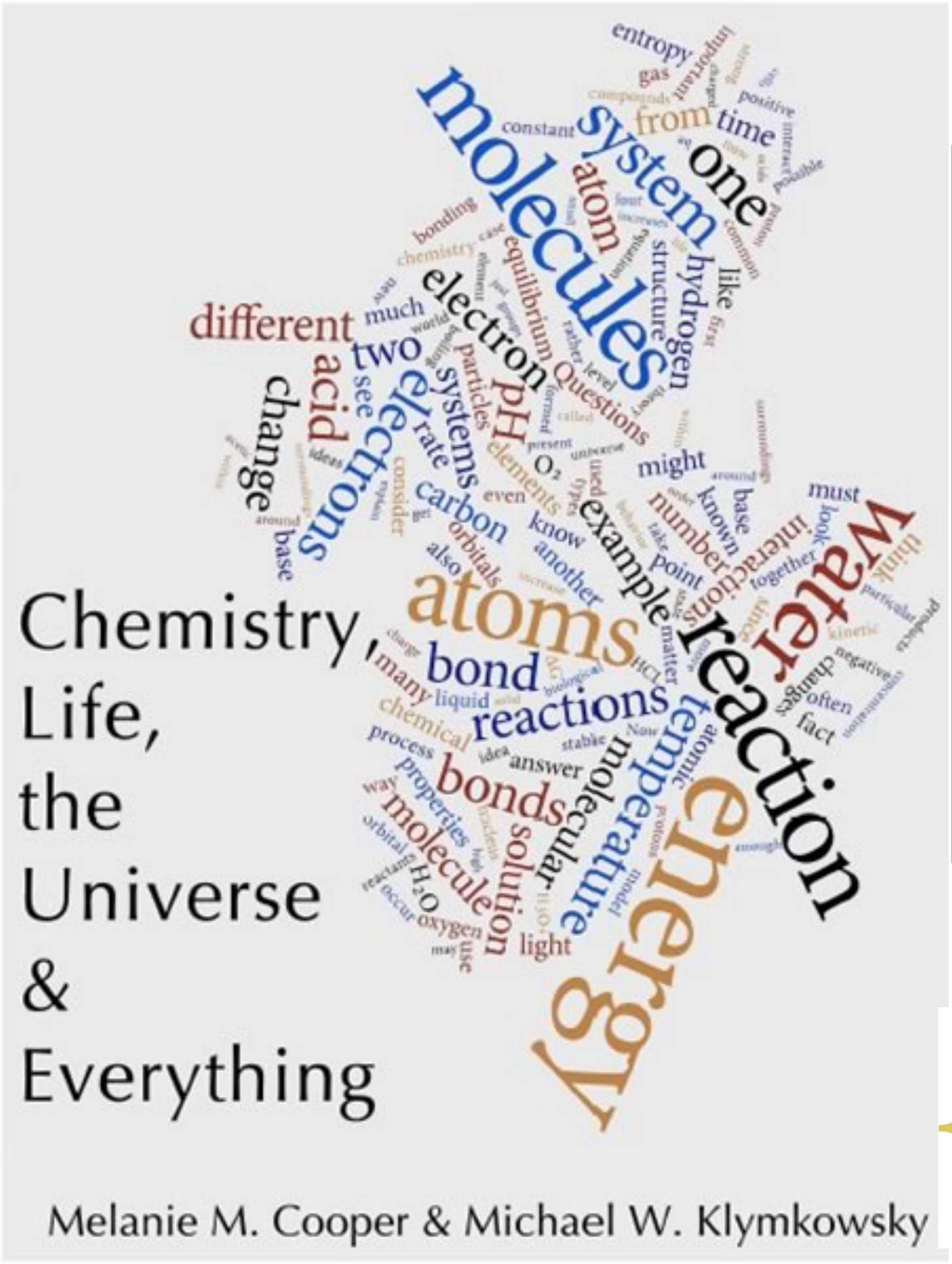
Focused around



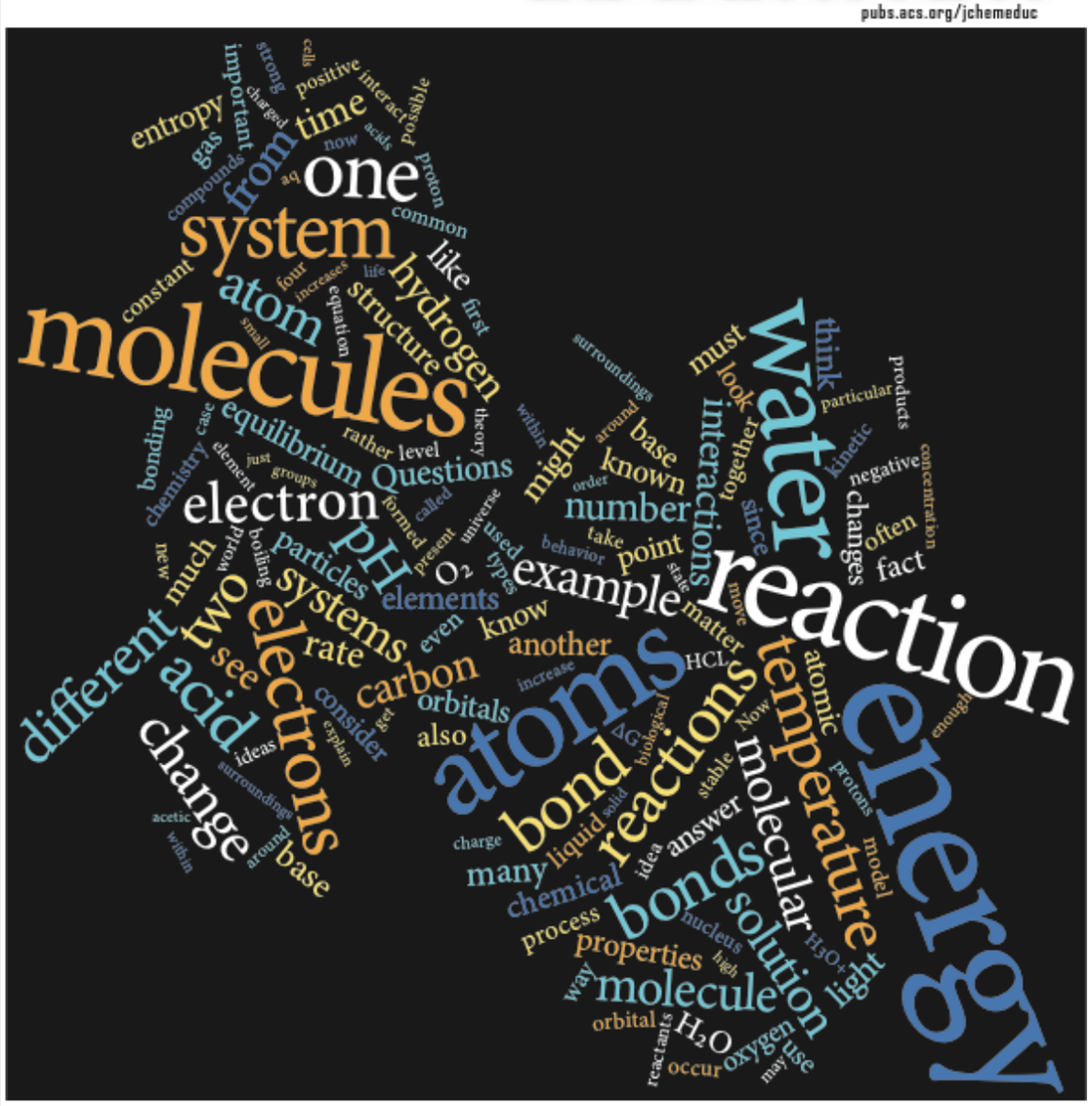
Chemistry, Life, the Universe, and Everything: A New Approach to General Chemistry, and a Model for Curriculum Reform

Melanie Cooper*† and Michael Klymkowsky‡
† Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, United States
‡ Molecular, Cellular and Developmental Biology and CU Teach, University of Colorado, Boulder, Colorado 80309, United States

engineering more effective courses: CLUE



JOURNAL OF CHEMICAL EDUCATION
VOLUME 90, NUMBER 9 • SEPTEMBER 2013
pubs.acs.org/jchemeduc



ACS Publications
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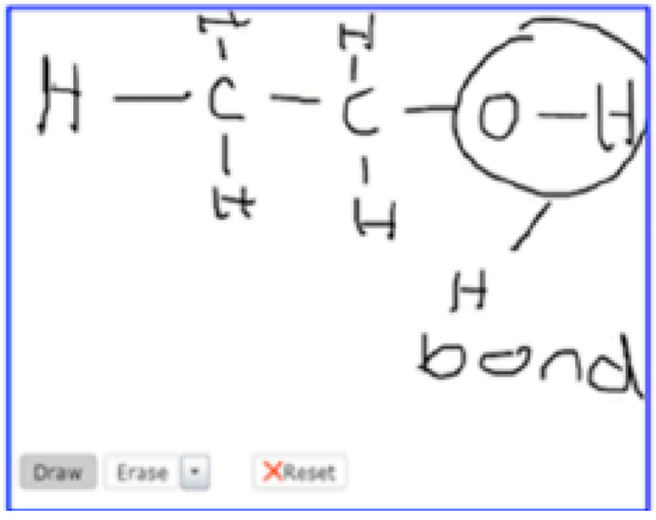
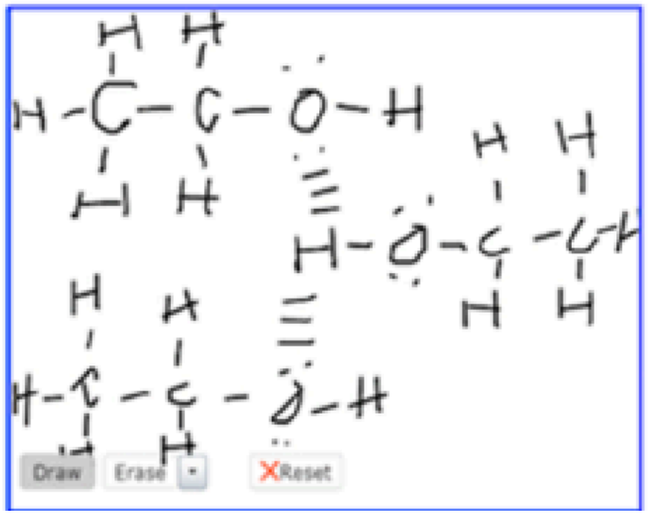
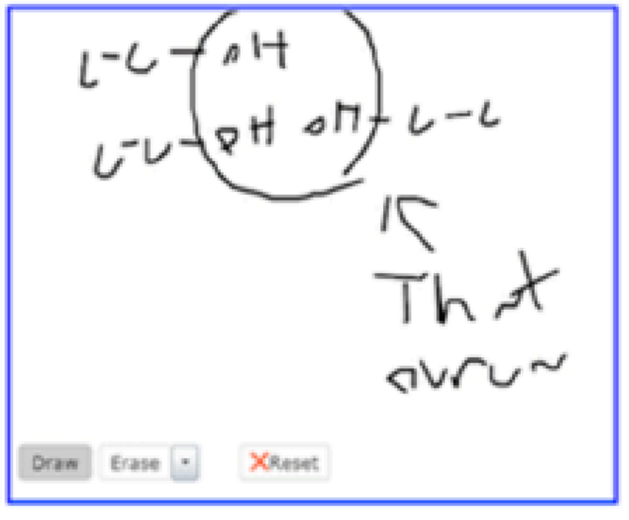
Division of Chemical Education, Inc.
American Chemical Society

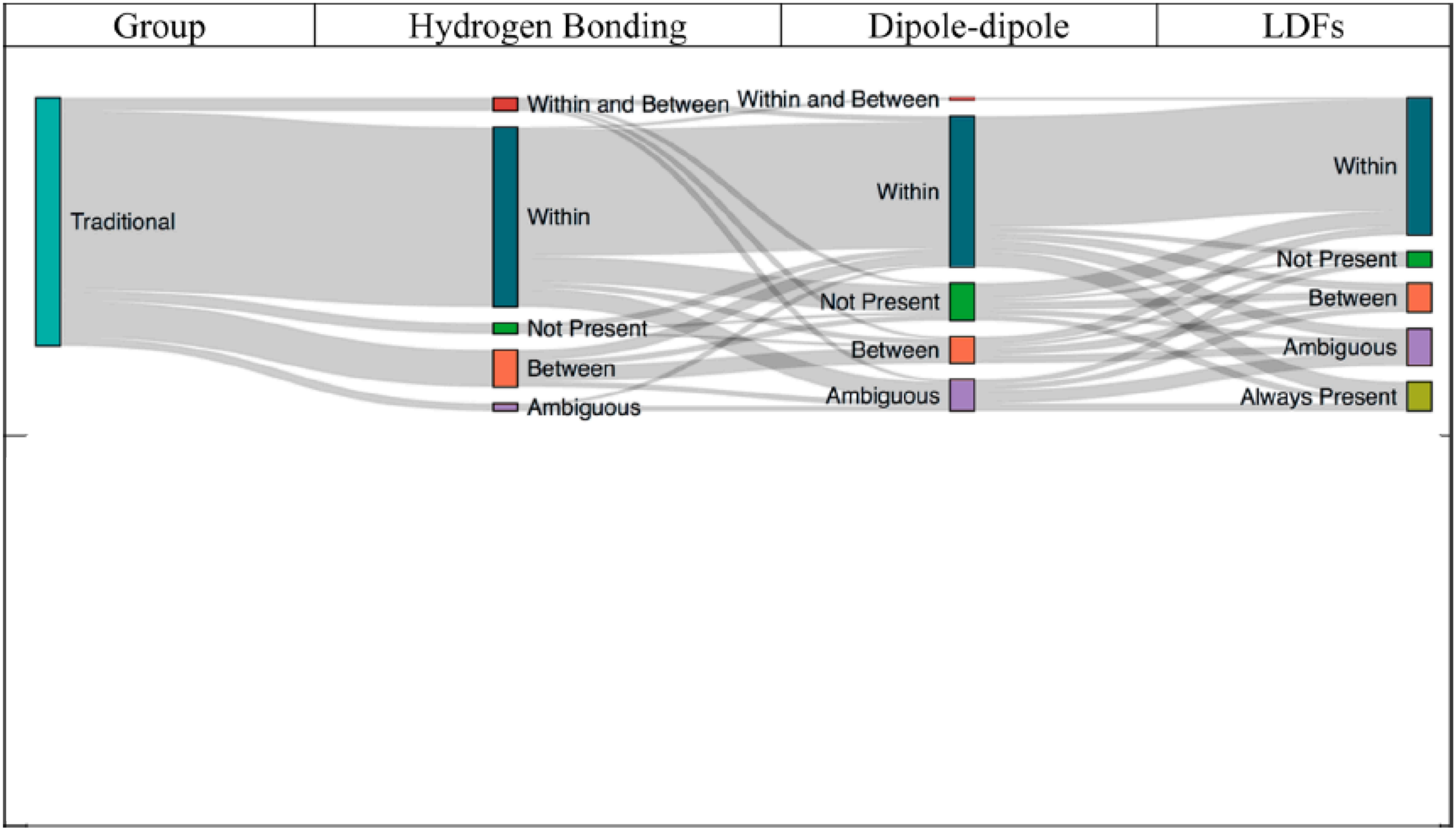
NSF

1: Atoms
2: Electrons & orbitals
3: Elements, bonding & ...
4: Heterogenous compounds
5: Systems thinking
6: Solutions
7: Chemical reactions
8: How far? how fast?
9: Reaction systems

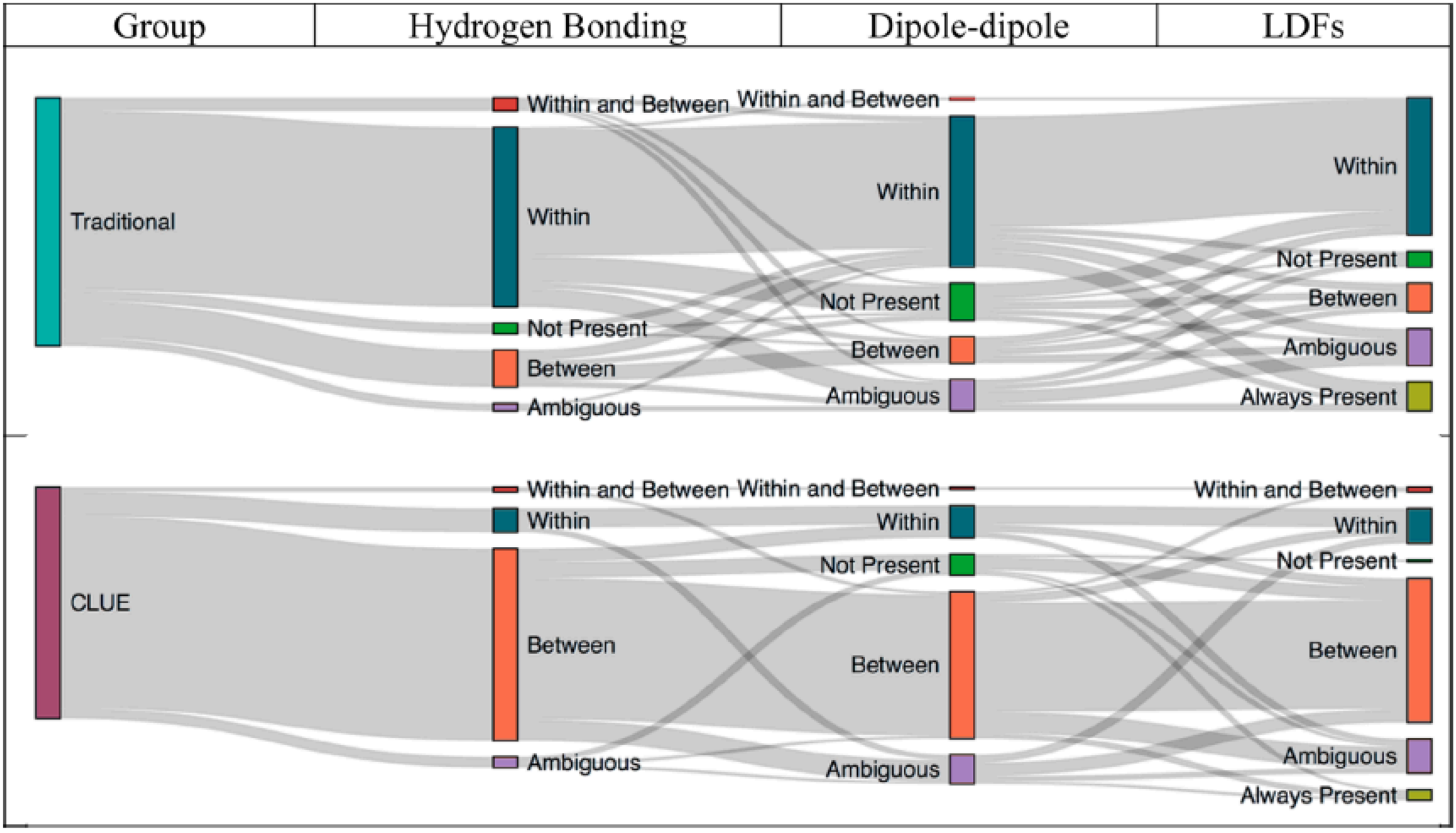
Types of analyses possible through beSocratic: intermolecular interactions

IMF Type	Code for IMFA Response Drawings Characterizing IMF Locations		
	Within the Molecule	Between Molecules	Ambiguous
Hydrogen Bonding			

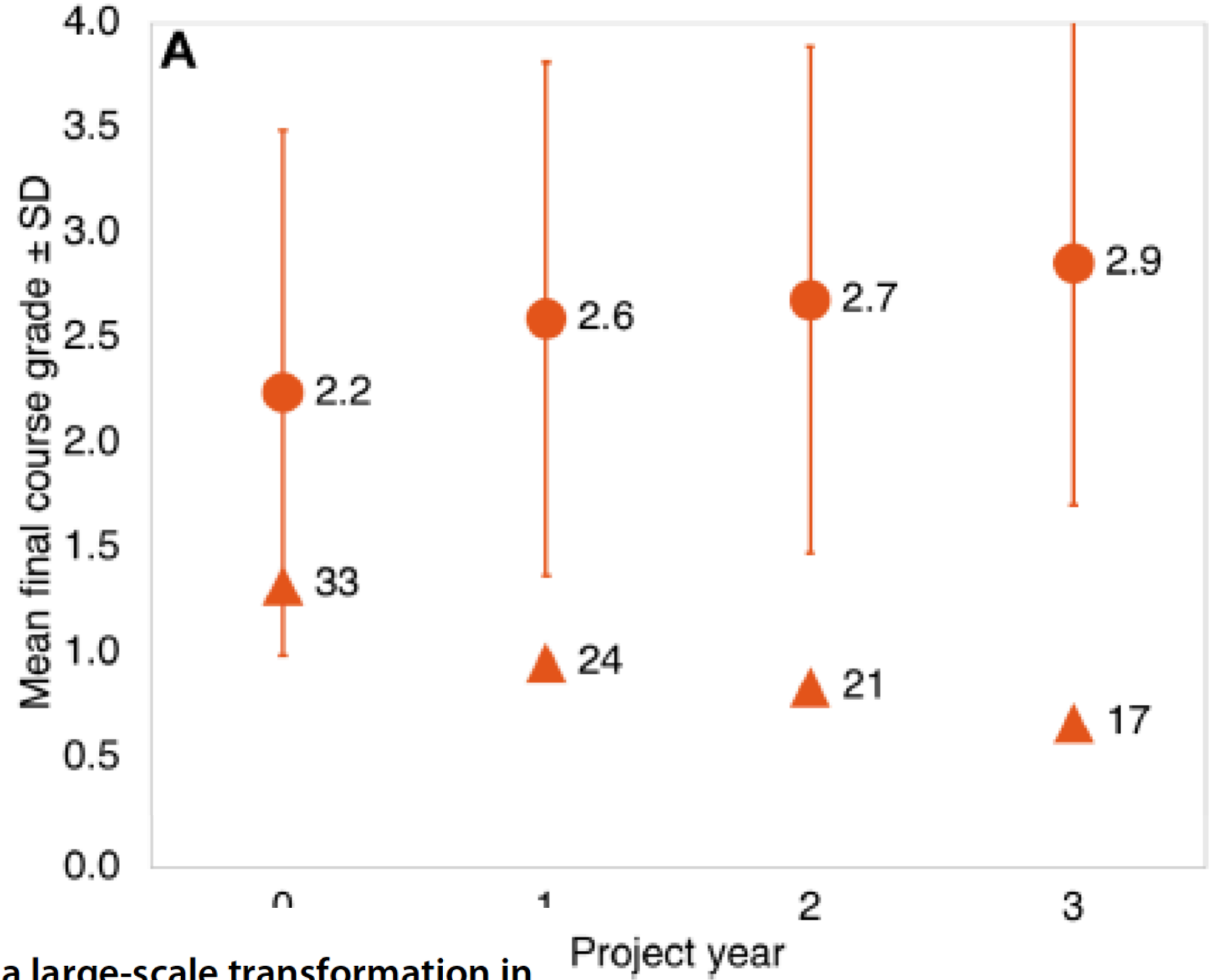
Type analysis possible through beSocratic: intermolecular interactions



Type analysis possible through beSocratic: intermolecular interactions



chemistry
(CLUE)



SOCIAL SCIENCE

Evaluating the extent of a large-scale transformation in gateway science courses

Rebecca L. Matz[1]*, Cori L. Fata-Hartley[2], Lynmarie A. Posey[3], James T. Laverty[4], Sonia M. Underwood[5], Justin H. Carmel[5], Deborah G. Herrington[6], Ryan L. Stowe[3], Marcos D. Caballero[7], Diane Ebert-May[8], Melanie M. Cooper[3]

engineering more effective courses: CLUE

Further evidence for the efficacy of CLUE

- Cooper, Underwood, Hilley & Klymkowsky, 2012. **Development and Assessment of a Molecular Structure and Properties Learning Progression**, J Chem Edu.
- Williams, Underwood, Klymkowsky, & Cooper. 2015 **Are Noncovalent Interactions an Achilles Heel in Chemistry Education? A Comparison of Instructional Approaches**. J. Chem Educ
- Cooper, Reyes-Gastelum, Underwood. 2016. **When do students recognize relationships between molecular structure and properties? A longitudinal comparison of the impact of traditional and transformed curricula**. CERP
- Crandell, Kouyoumdjian, Underwood & Cooper, 2018. **Reasoning about acid-base reactions in organic chemistry - it starts in general chemistry**, J Chem Ed. 2018.

we could stop here or …

integrating CLUE + OCLUE

Design

connect topics to core ideas by using scientific practices.

National Research Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; National Academies Press: Washington, DC, 2012.

Focus on biologically relevant material

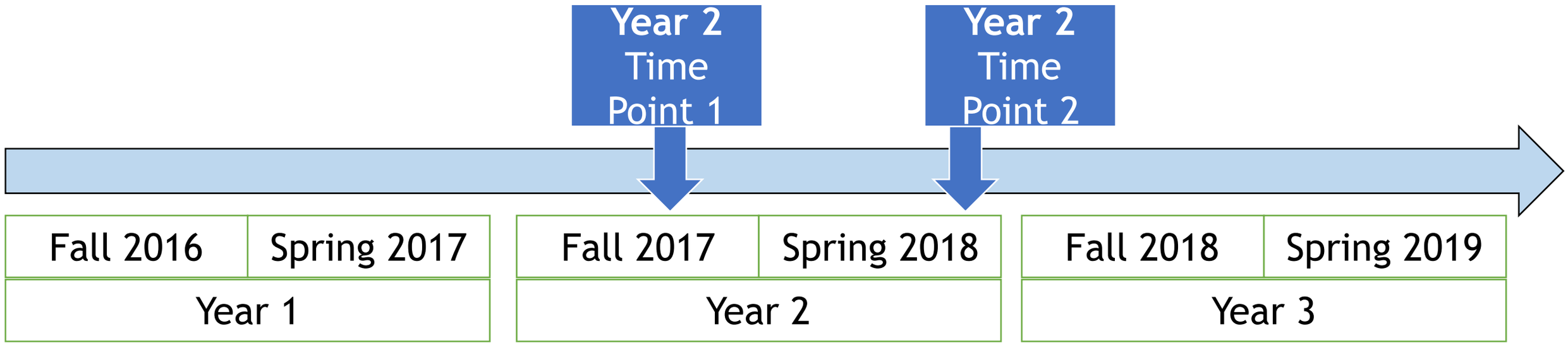
outcomes data from the Cooper group

Traditional Organic Chemistry

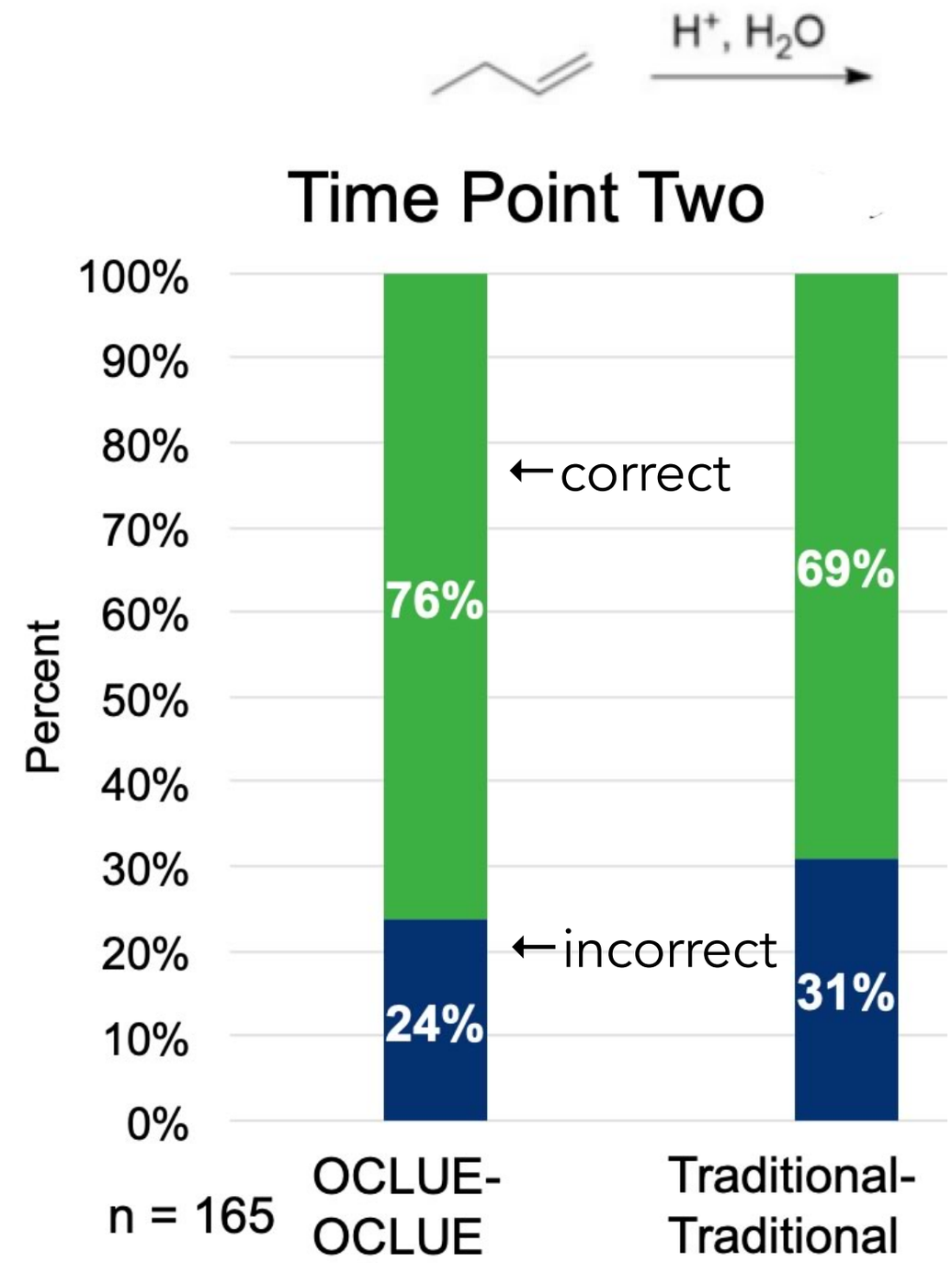
Participants

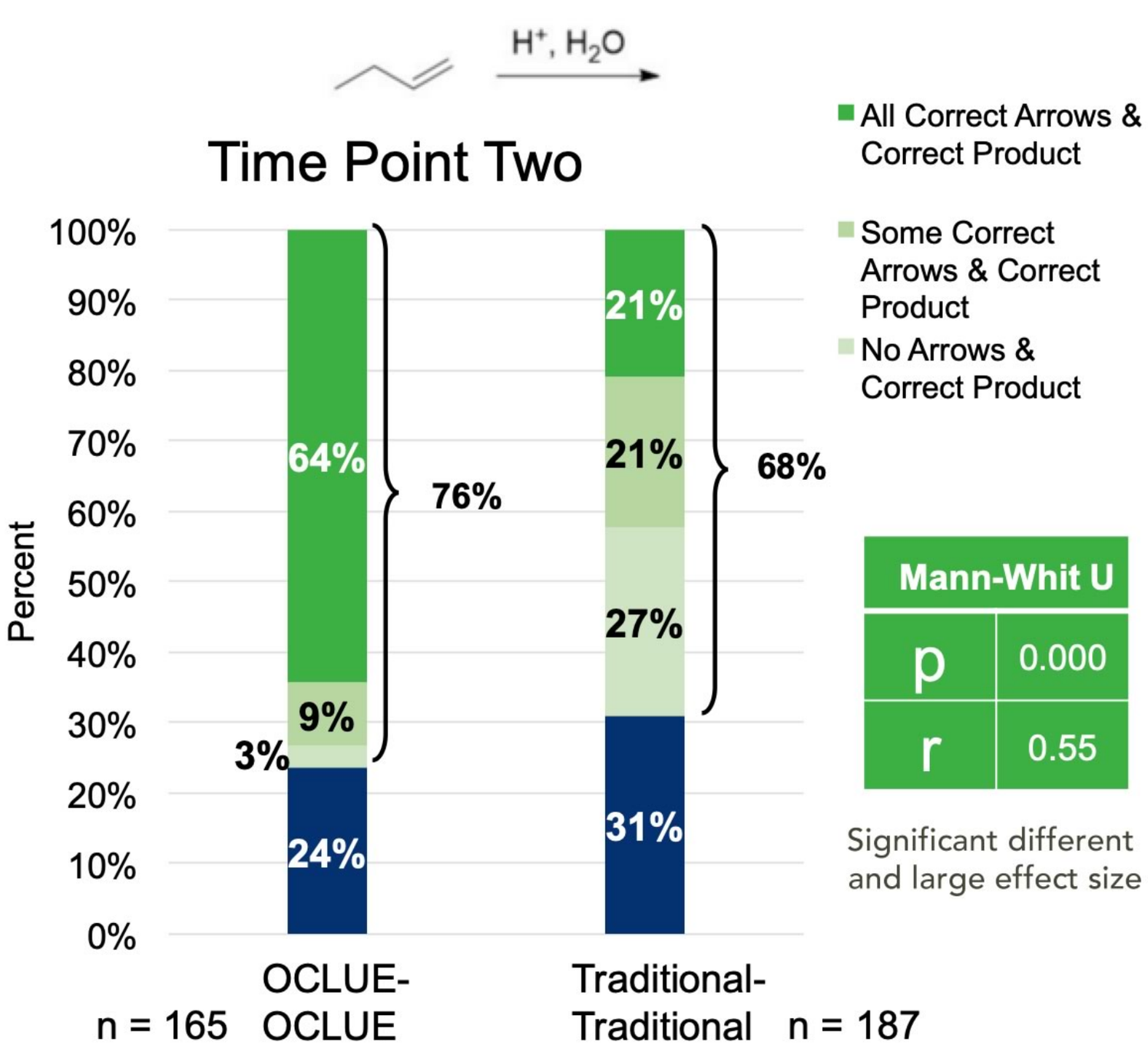
Mostly Pre-professional majors
~75% female

Compared on:
ACT score
GC1 Grade
GC2 Grade
OC1 Grade
OC2 Grade
GPA Prior to OC1



outcomes data from the Cooper group





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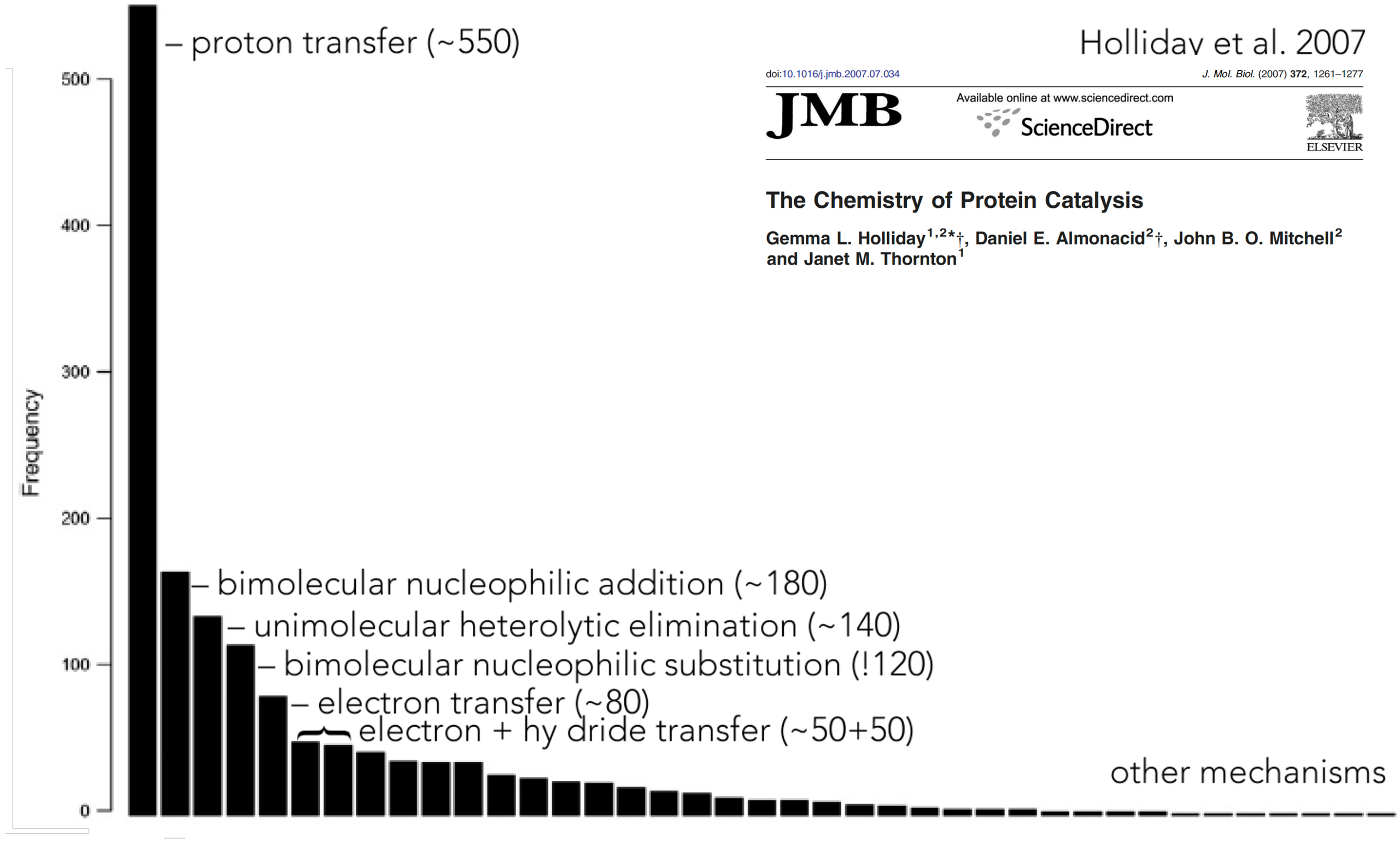

Hollidav et al. 2007

doi:10.1016/j.jmb.2007.07.034 *J. Mol. Biol.* (2007) **372**, 1261–1277

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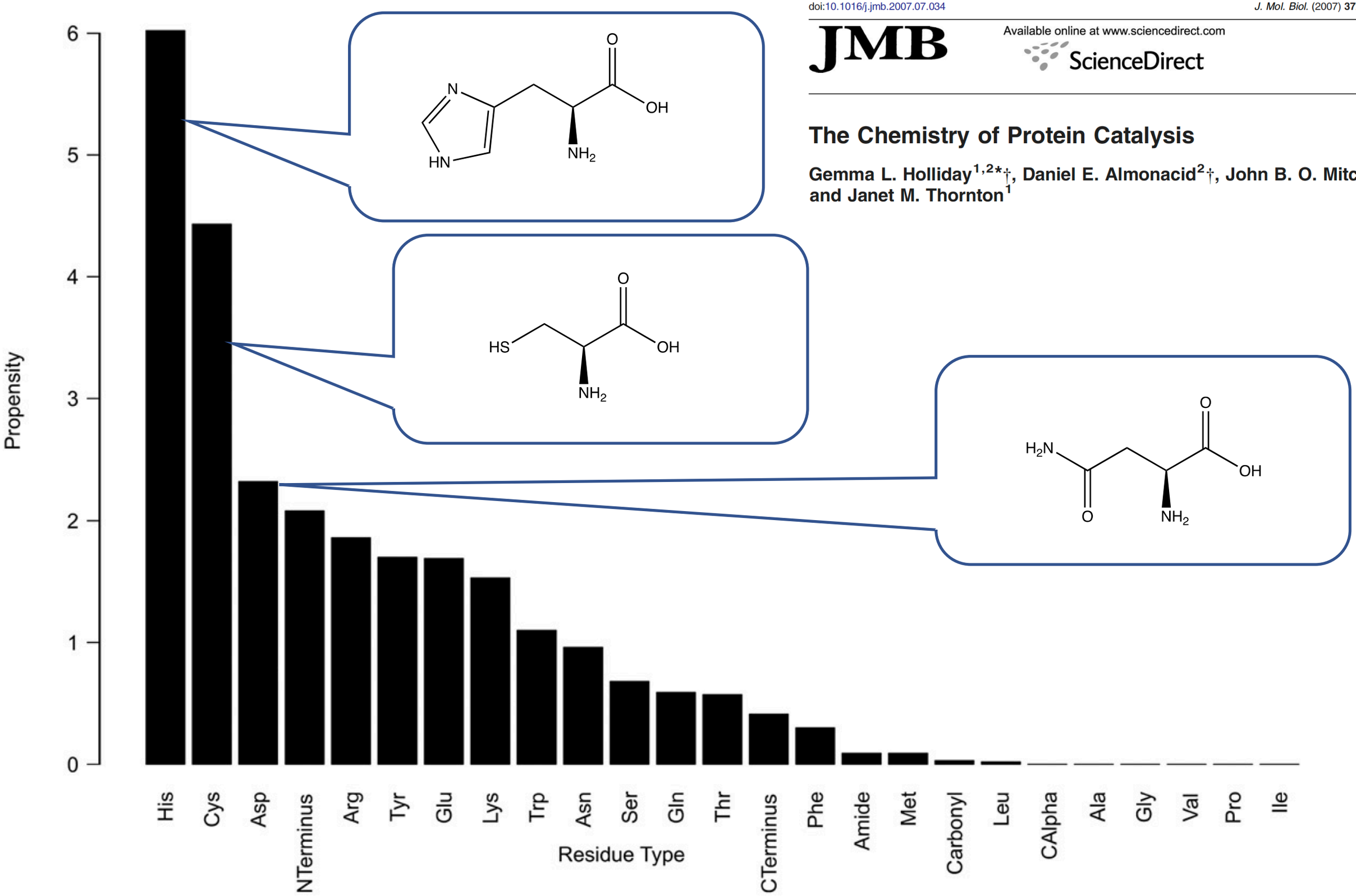

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Why does it all matter?

Poorly designed courses are discriminatory

UNDERGRADUATE SCIENCE

Weed-Out Courses Hamper Diversity

The time-honored practice of using introductory courses to weed out students seeking degrees in science and engineering hinders efforts to attract more women and minorities into those fields, say the chairs of science departments at U.S. universities. But the professors see no need to change their approach to teaching.

That contradiction appears in a survey by the Bayer Foundation, the 15th in its annual series on science education. More than 400 chairs from the top-200 research universities and from minority-serving institutions responded to a series of questions on their attitudes toward underrepresented minorities (African-Americans, Hispanics, and Native Americans) and women. It's a follow-up to last year's survey asking those students about the obstacles they face in pursuing STEM (science, technology, engineering, and mathematics) degrees.

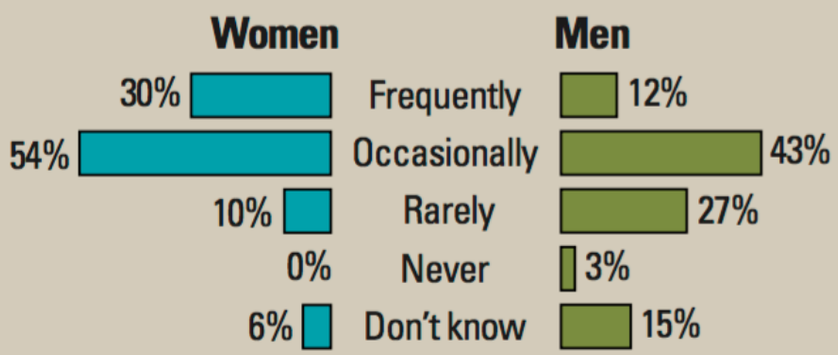
The new survey (bayerus.com) found that 84% of the science chairs say broadening participation in STEM fields is important to their

courses are taught. There's a growing literature indicating that student collaborations, interactive technology, and hands-on learning are more effective in reaching students than are the traditional lecture and by-the-numbers lab sessions. But Hrabowski says many faculty members don't have the time, resources, or institutional support to try anything new.

Some faculty members also assume erroneously that they must lower the bar in order to have more students succeed. Their con-

Discouraging Words

Do you believe inappropriate discouragement of women and minorities still occurs?

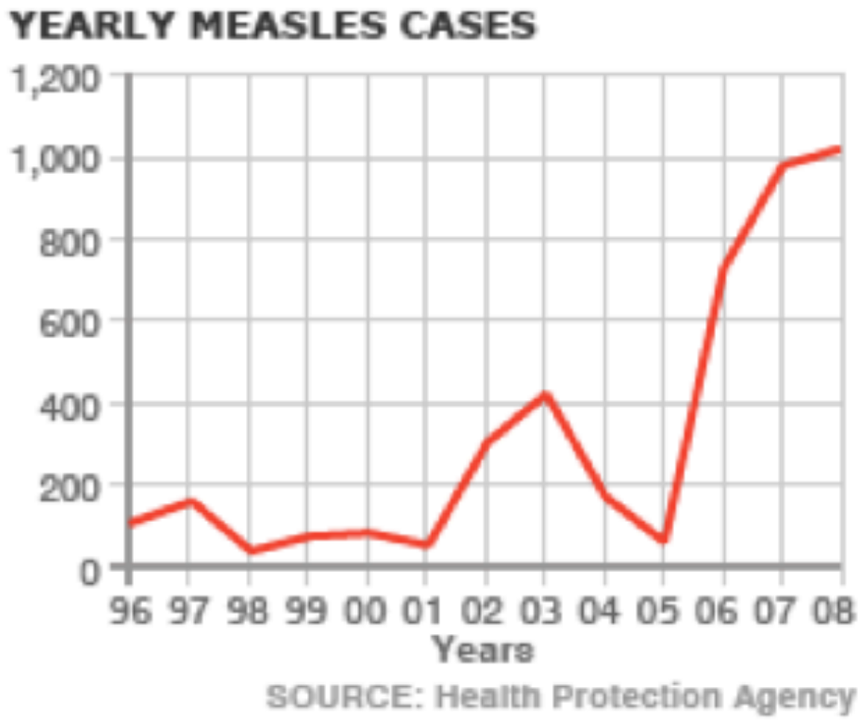


Two perspectives. Most women chairs reported that women and minority students face roadblocks on their way to a STEM degree.

Mervis 2011. Weed-out courses hamper diversity." Science **334**: 1333-1333.

Reduced MMR Equals More Measles

Reduced uptake of the MMR vaccine, fueled no doubt by anti-vaccine propaganda, has resulted in a recent **significant increase in Measles in the UK** as shown by the graph on the right. And despite what the anti-vaccine twits will tell you, Measles can be a very serious disease. According to the **CDC**:



Uganda

US pastor runs network giving 50,000 Ugandans bleach-based 'miracle cure'

Revealed: group led by Robert Baldwin and part-funded by Sam Little claims toxic fluid will eradicate HIV/Aids and other diseases

“Montaigne concludes, like Socrates, that
ignorance aware of itself is the only true knowledge”

- from “Forbidden Knowledge” by Roger Shattuck