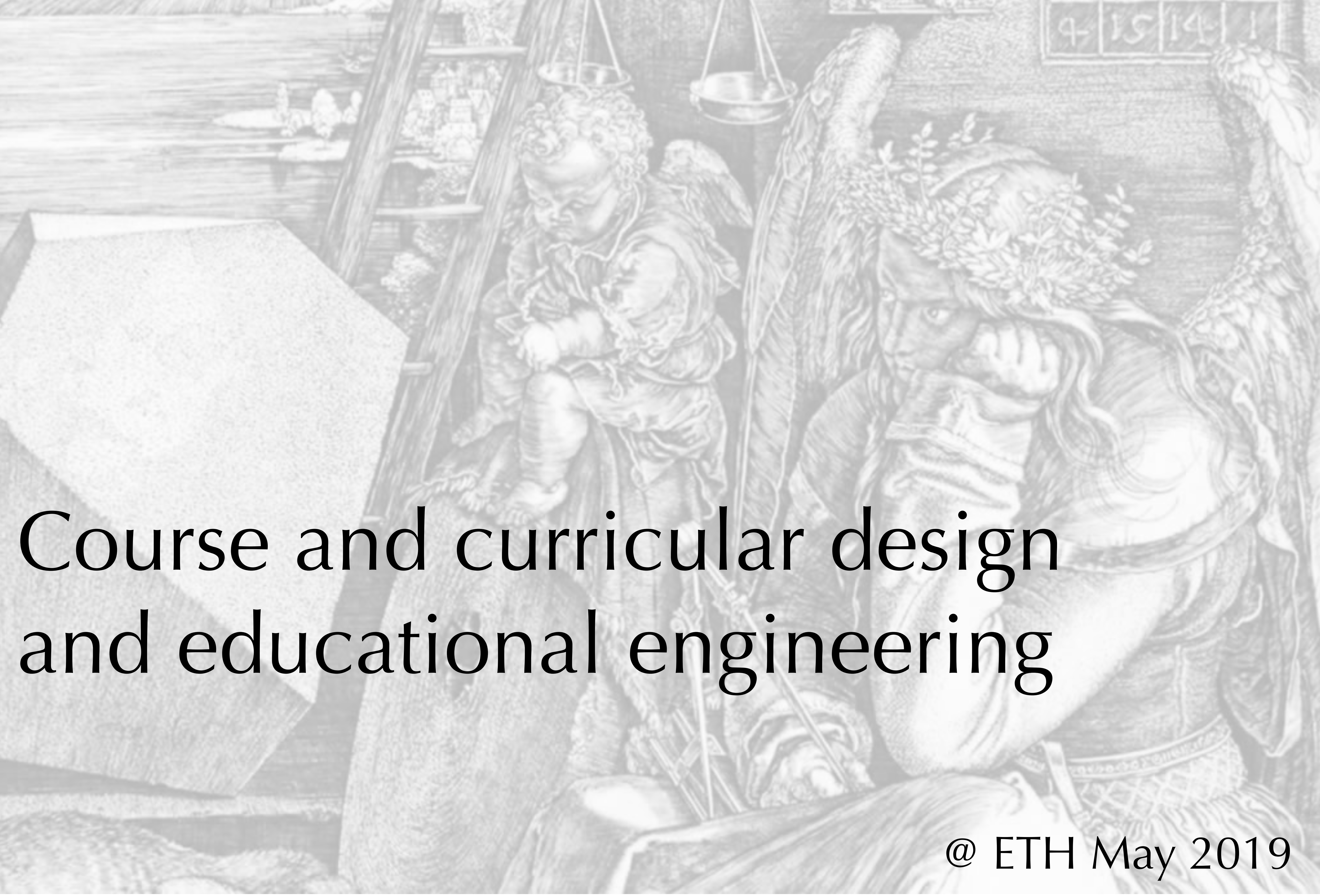


Course and curricular design and educational engineering

@ ETH May 2019

Mike Klymkowsky
Molecular, Cellular & Developmental Biology University of Colorado Boulder

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

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

BeSocratic

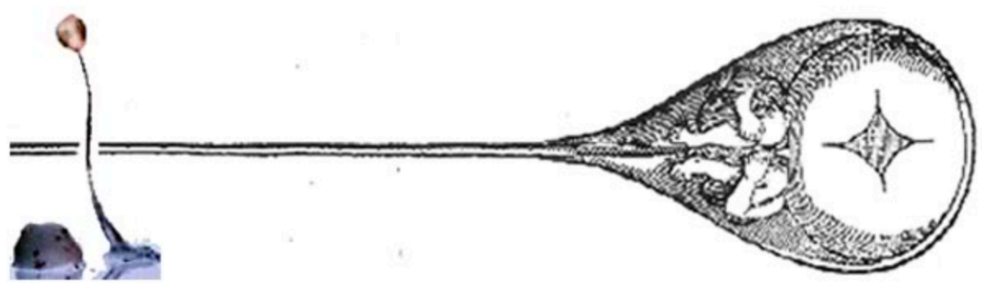
people I need to thank

I will consider:

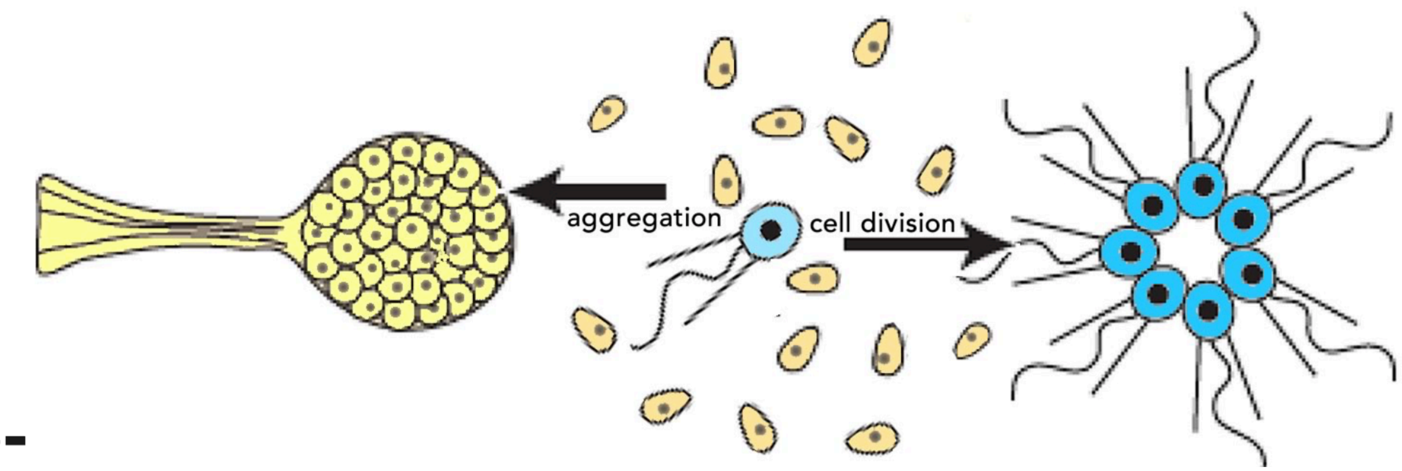
- How do we approach the redesign of course materials to enhance student engagement and educational effectiveness
- consider whether …
  - is what you teach is what students need?
  - do you explain why what is taught is important?
  - do you emphasize recurrent themes?
  - do your exams reveal what you think students should be able to do?

An example (in progress): Developmental Biology

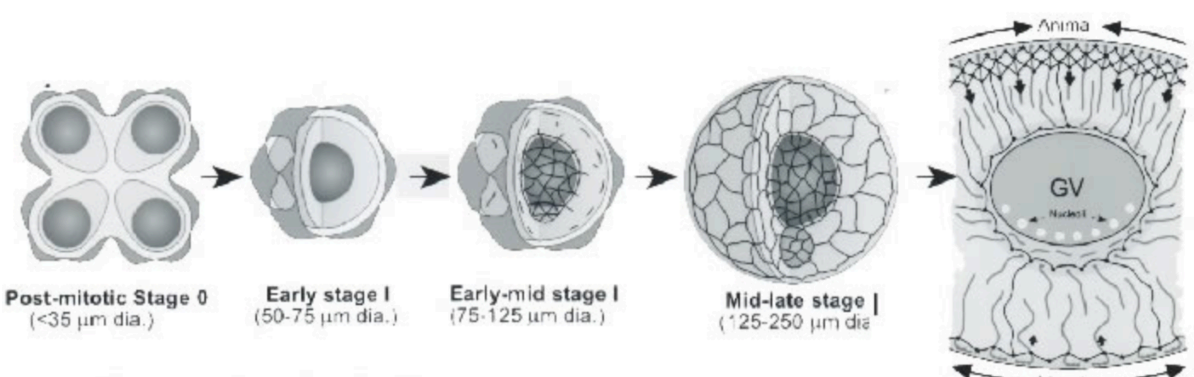
On teaching developmental biology in the 21st century (a devo-biofundamentals perspective)



Aggregative and clonal metazoans (a biofundamentals perspective)

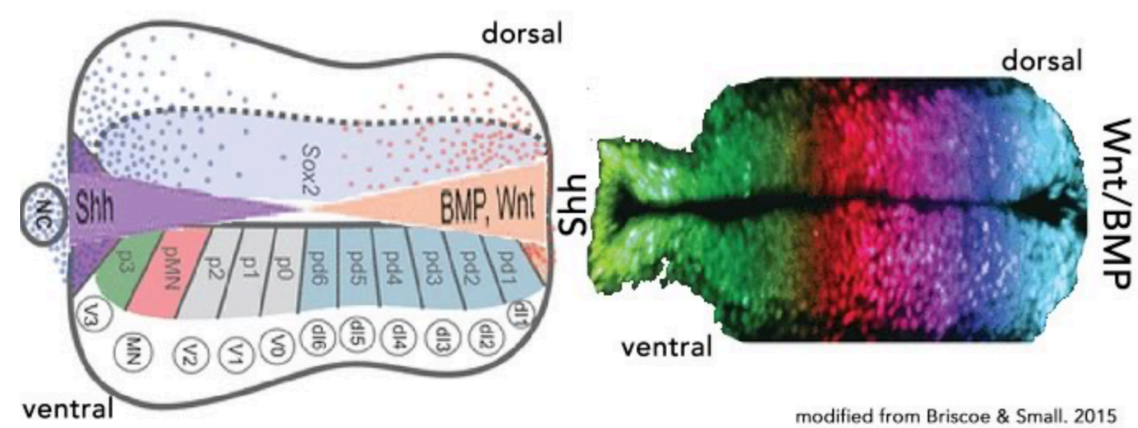


Establishing Cellular Asymmetries (a devo-biofundamentals perspective)



adapted from Gard & Klymkowsky, 1998

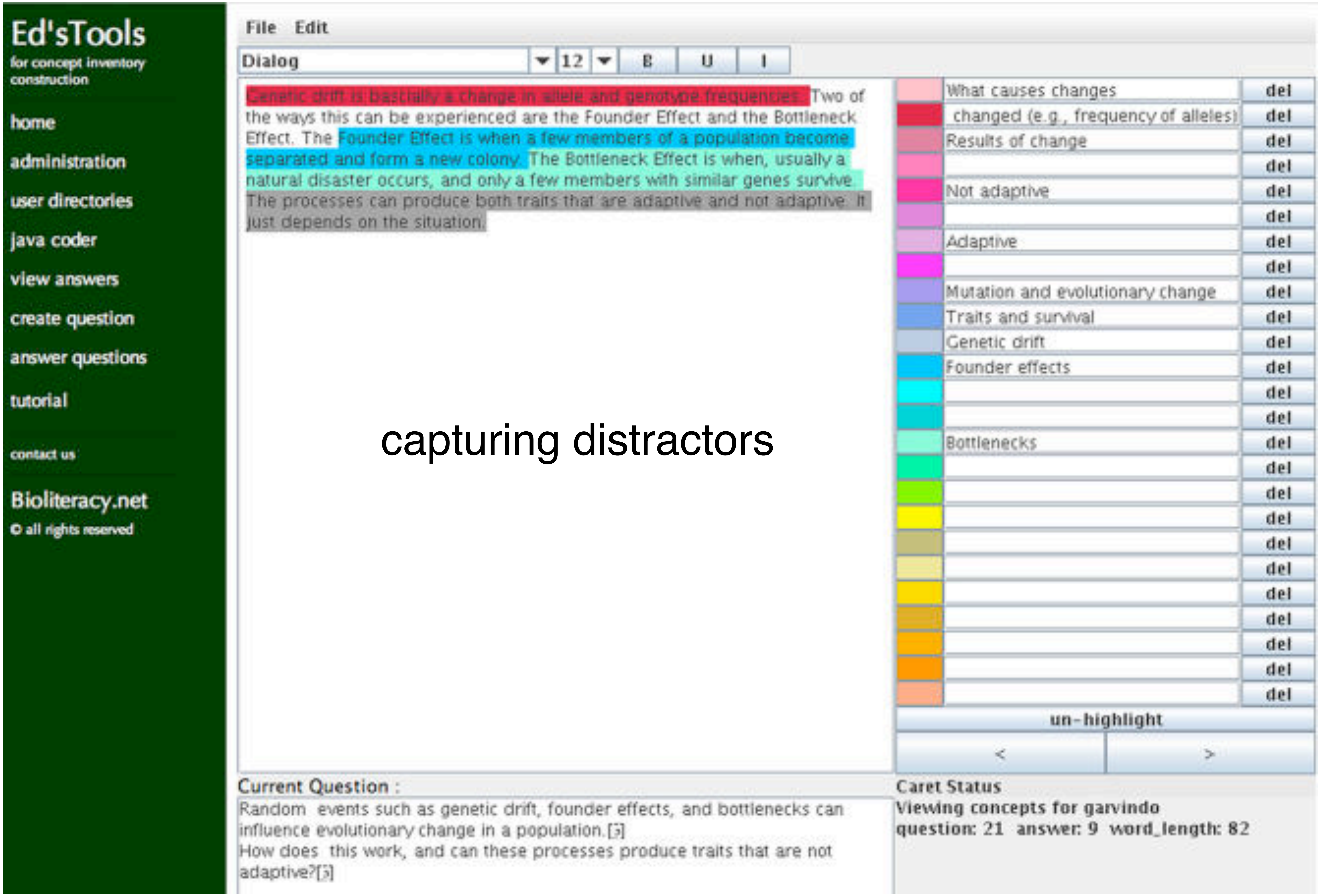
Gradients and Molecular Switches (a biofundamentalist perspective)



modified from Briscoe & Small, 2015

Where to start?

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



capturing distractors

concept tests

What makes DNA a good place to store information?

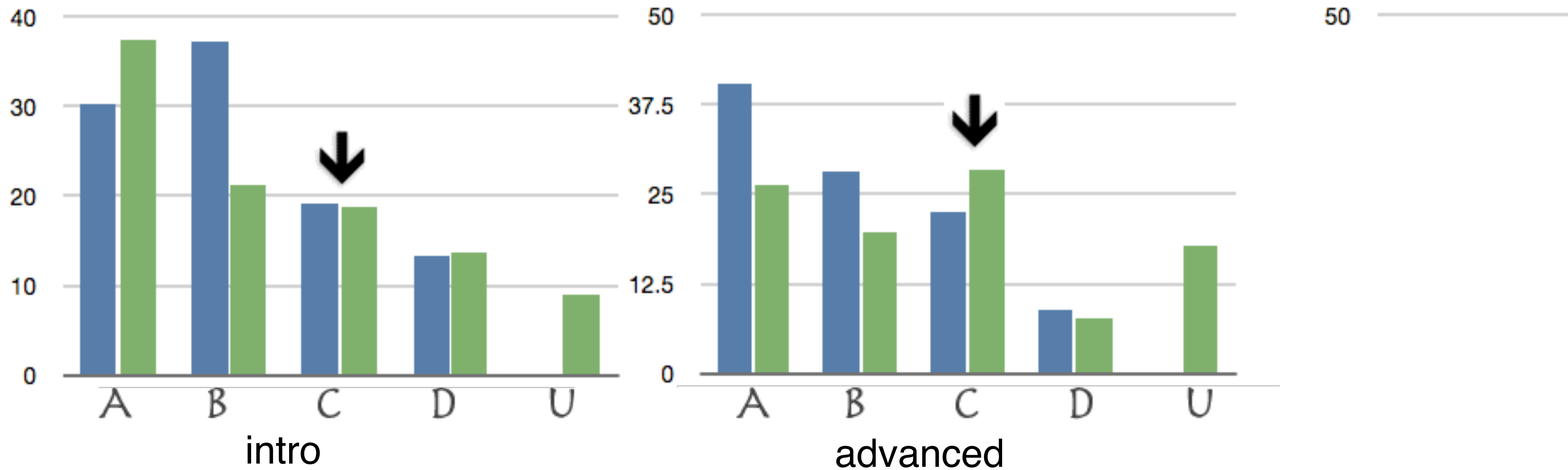
The hydrogen bonds that hold it together are very stable and difficult to break.

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%



concept tests

"… 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. it is difficult for instructors to predict what students are thinking
2. different groups of students may hold different ideas
3. concept test are of limited use as measures of learning
4. but can be useful for identifying concepts <u>**not**</u> taught effectively

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

BeSocratic : revealing student thinking

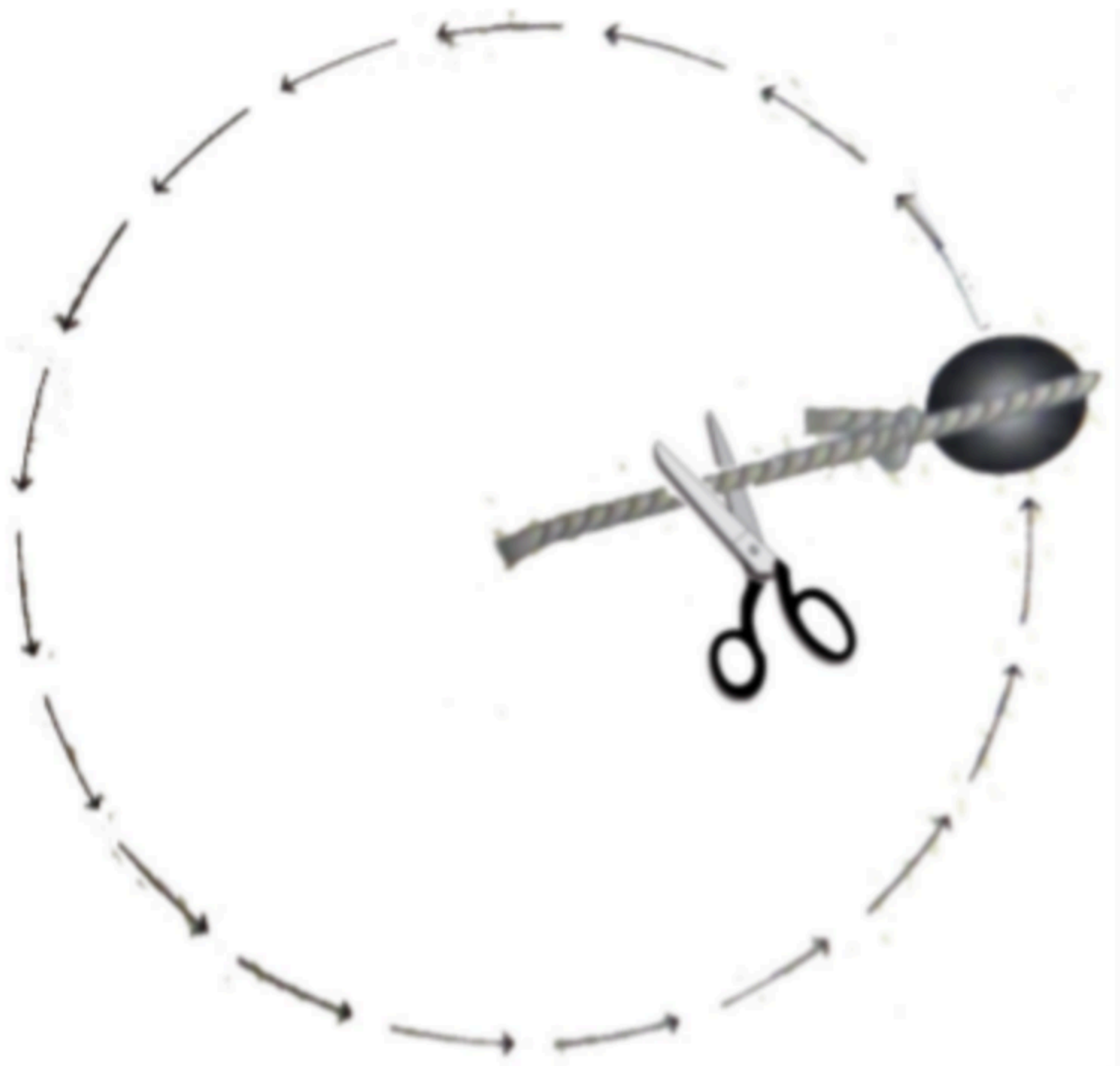
A Short History of the Use of Technology To Model and Analyze Student Data for Teaching and Research

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]

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

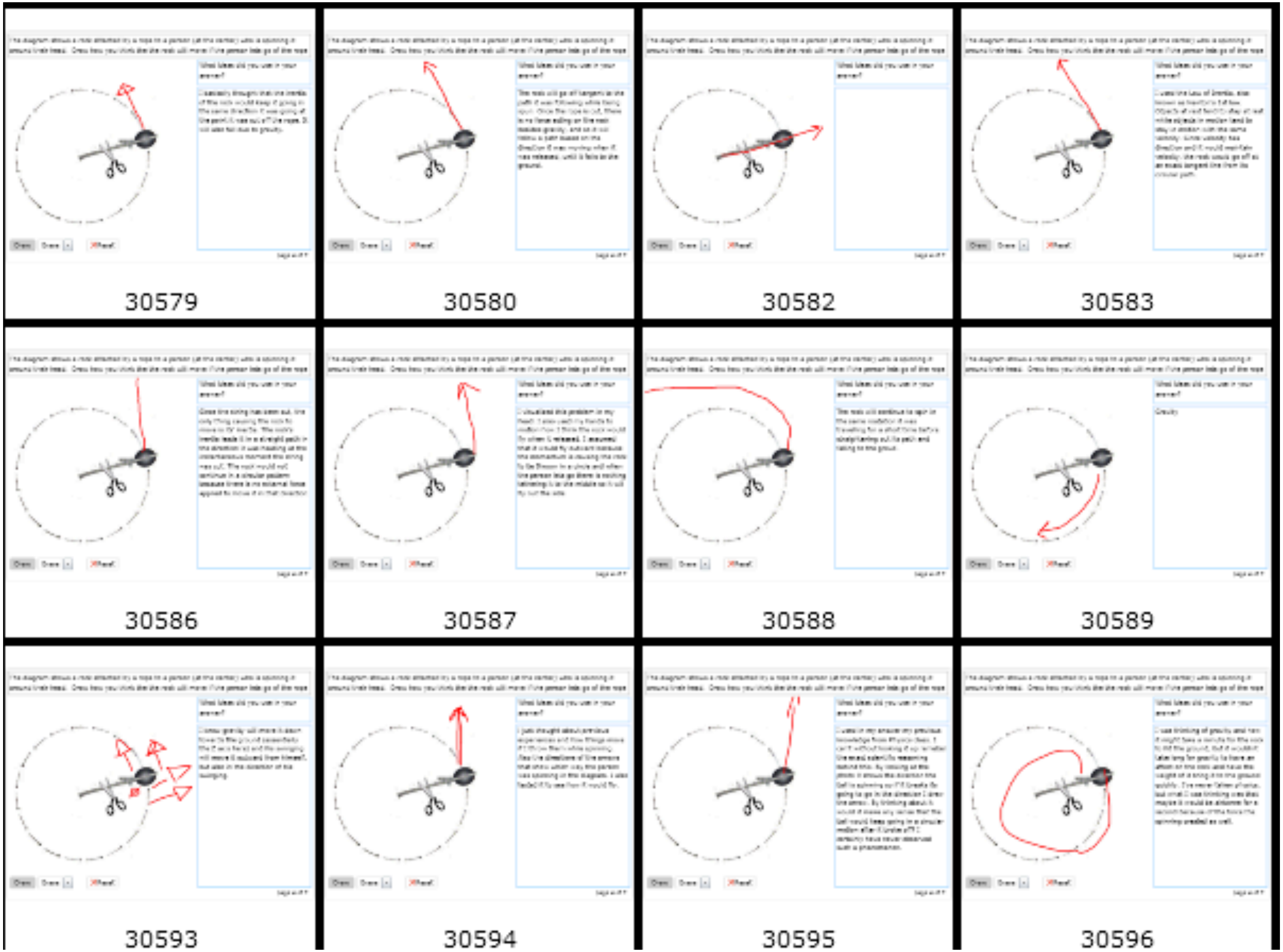
What ideas did you use in your answer?

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

What ideas did you use in your answer?

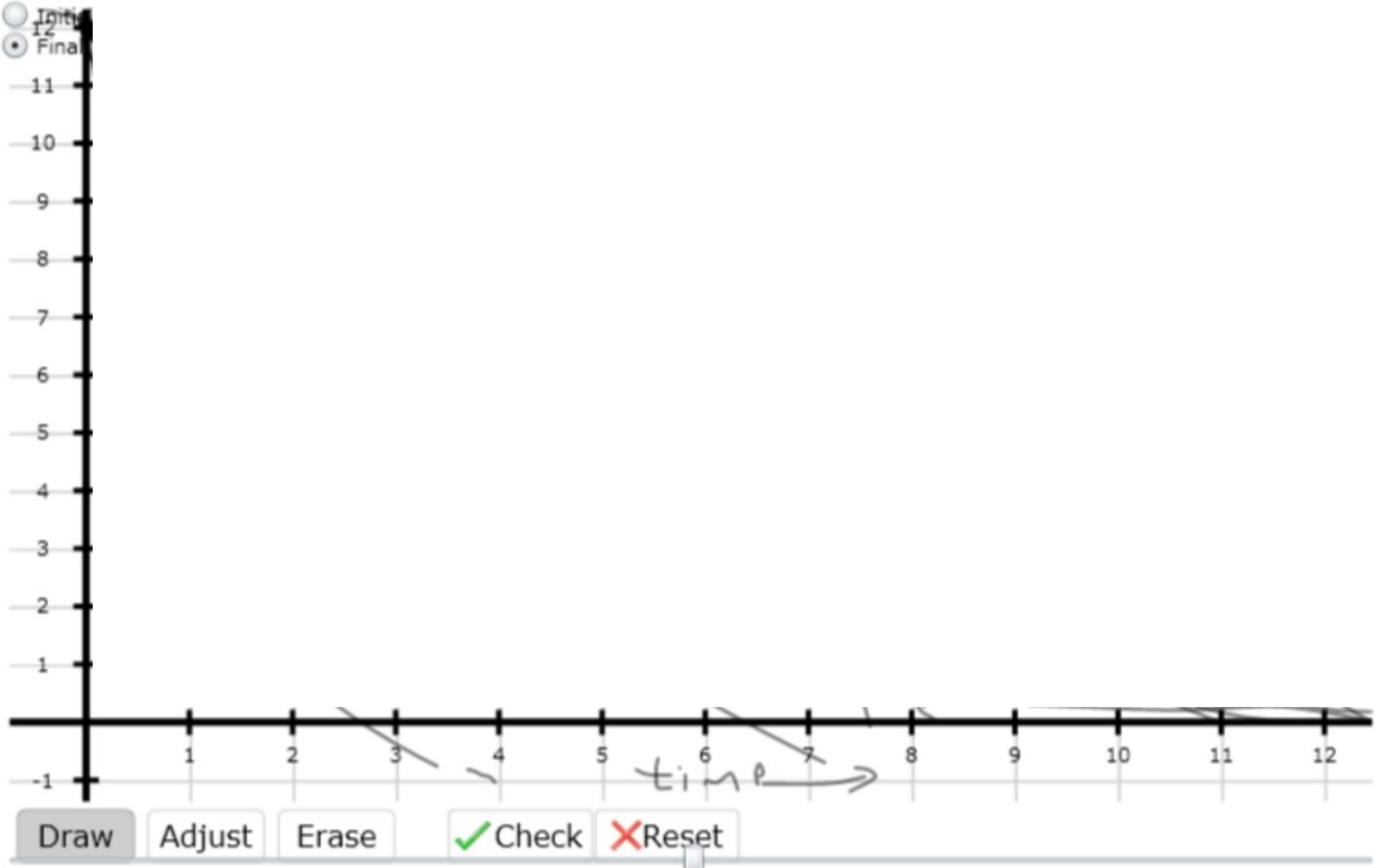
Draw Erase Reset

revealing student thinking

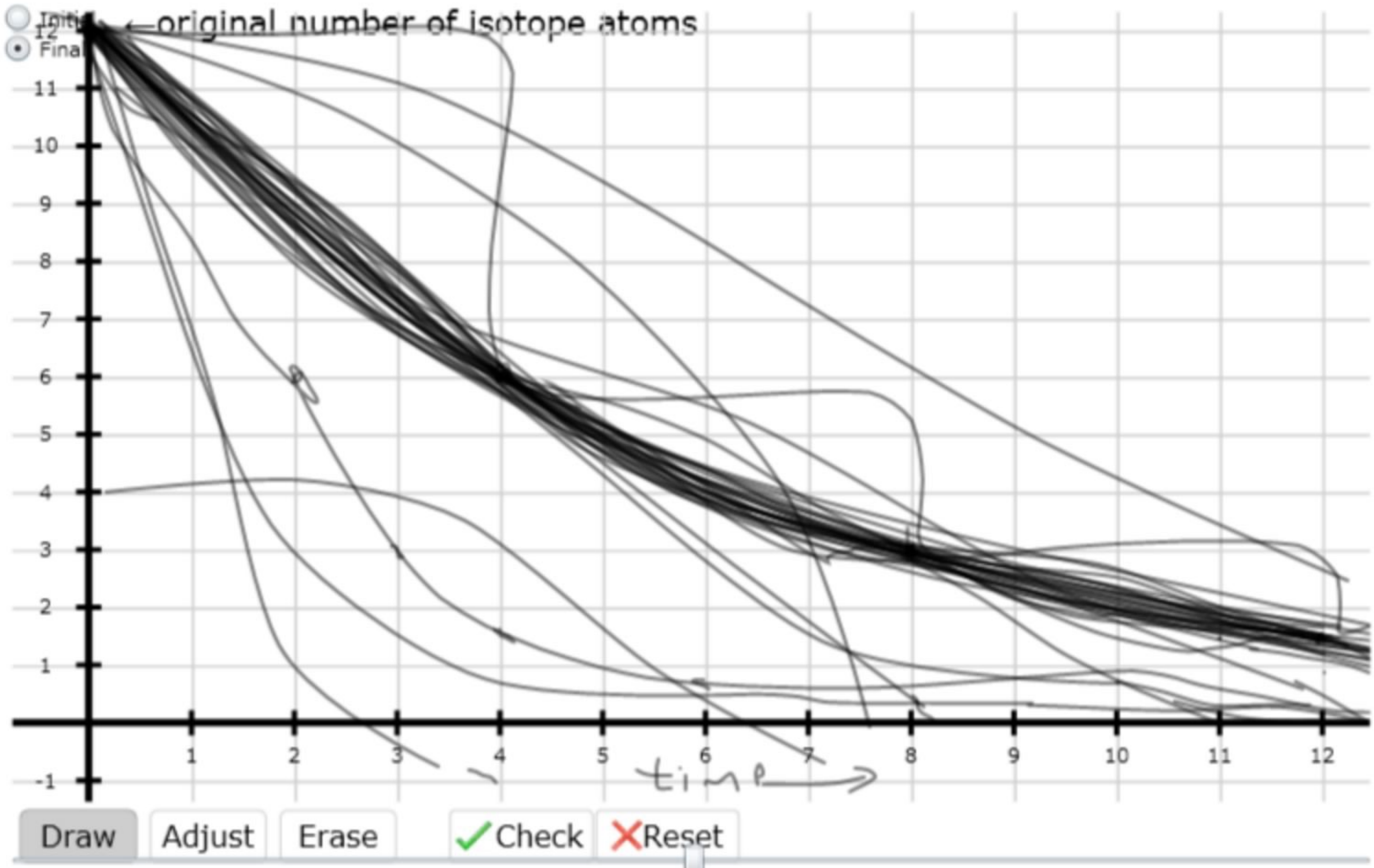


revealing student thinking

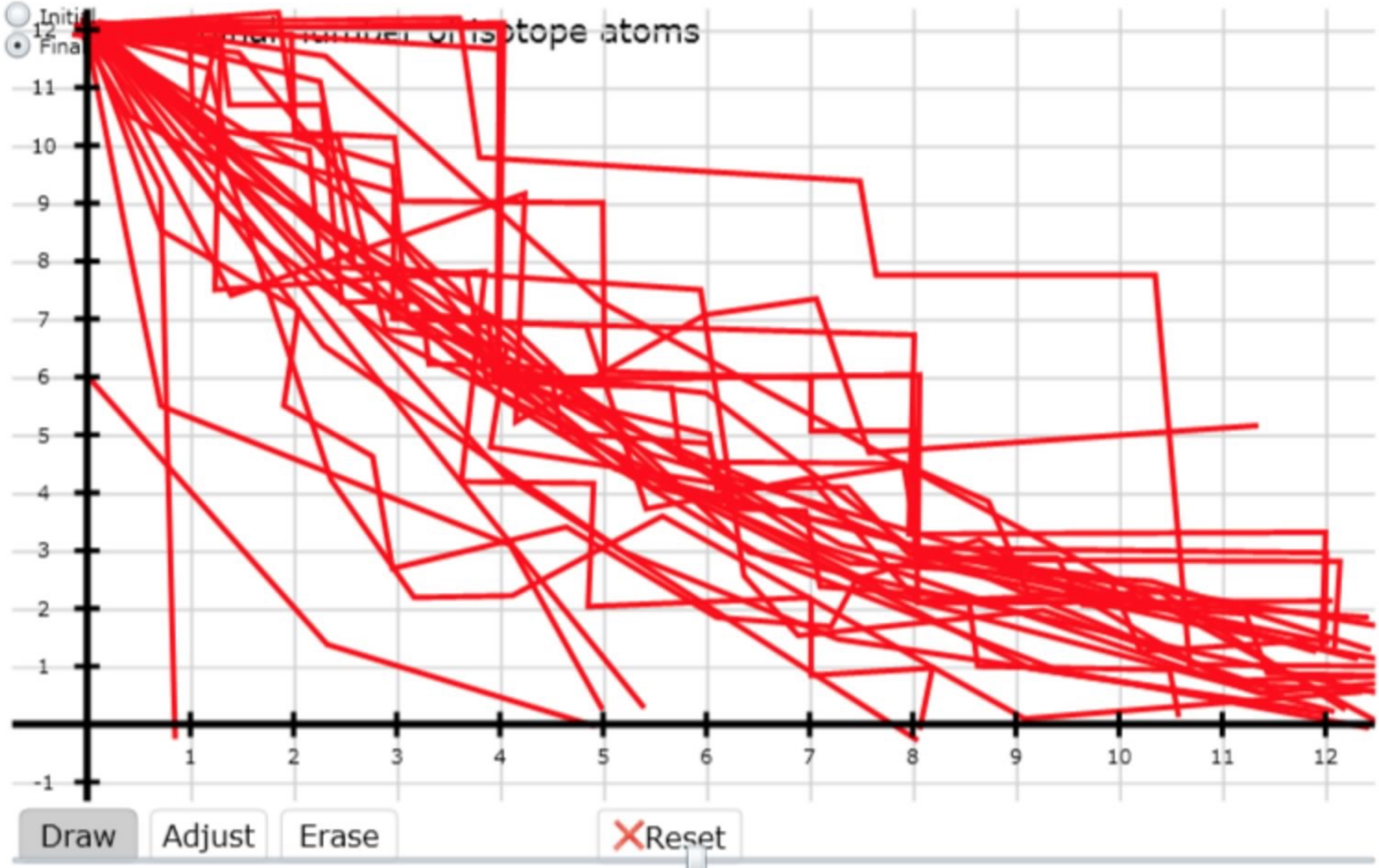
2.2: Now draw the half-life relationship graphically. The half-life of this isotope is 4 time units and you begin with 12,000,000,000 isotope atoms



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.

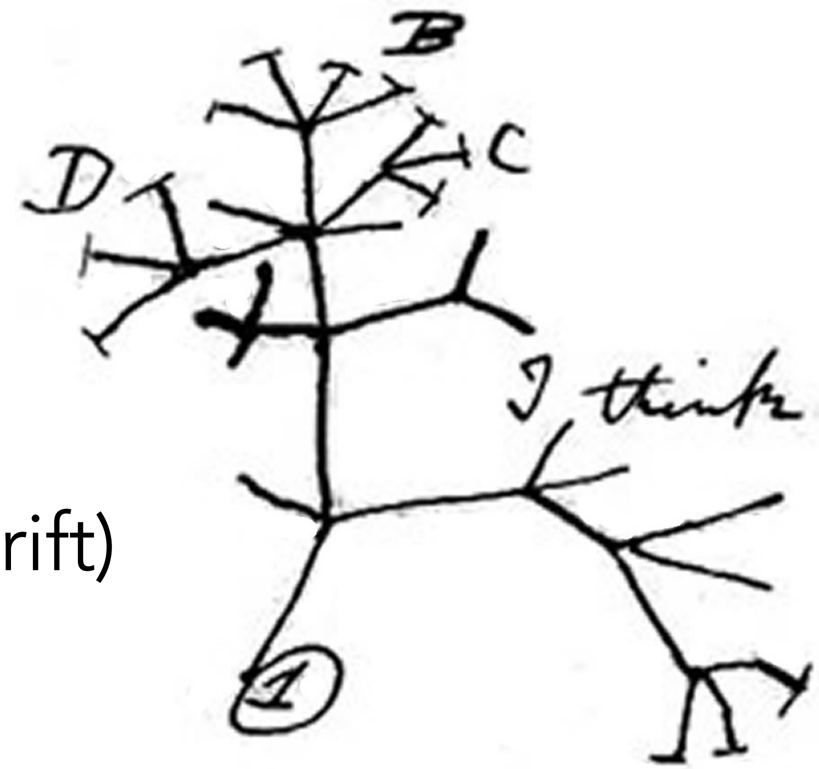


biofundamentals: an alternative introductory sequence

Existing MCDB course

- no discussion of
  - evolutionary mechanisms (social processes)
  - stochastic processes
- Lack of recurrent themes
  - course built first as interactive web site
  - transformed into an open source book
    - two semester version available free on-line
      - comments welcome!!!

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].

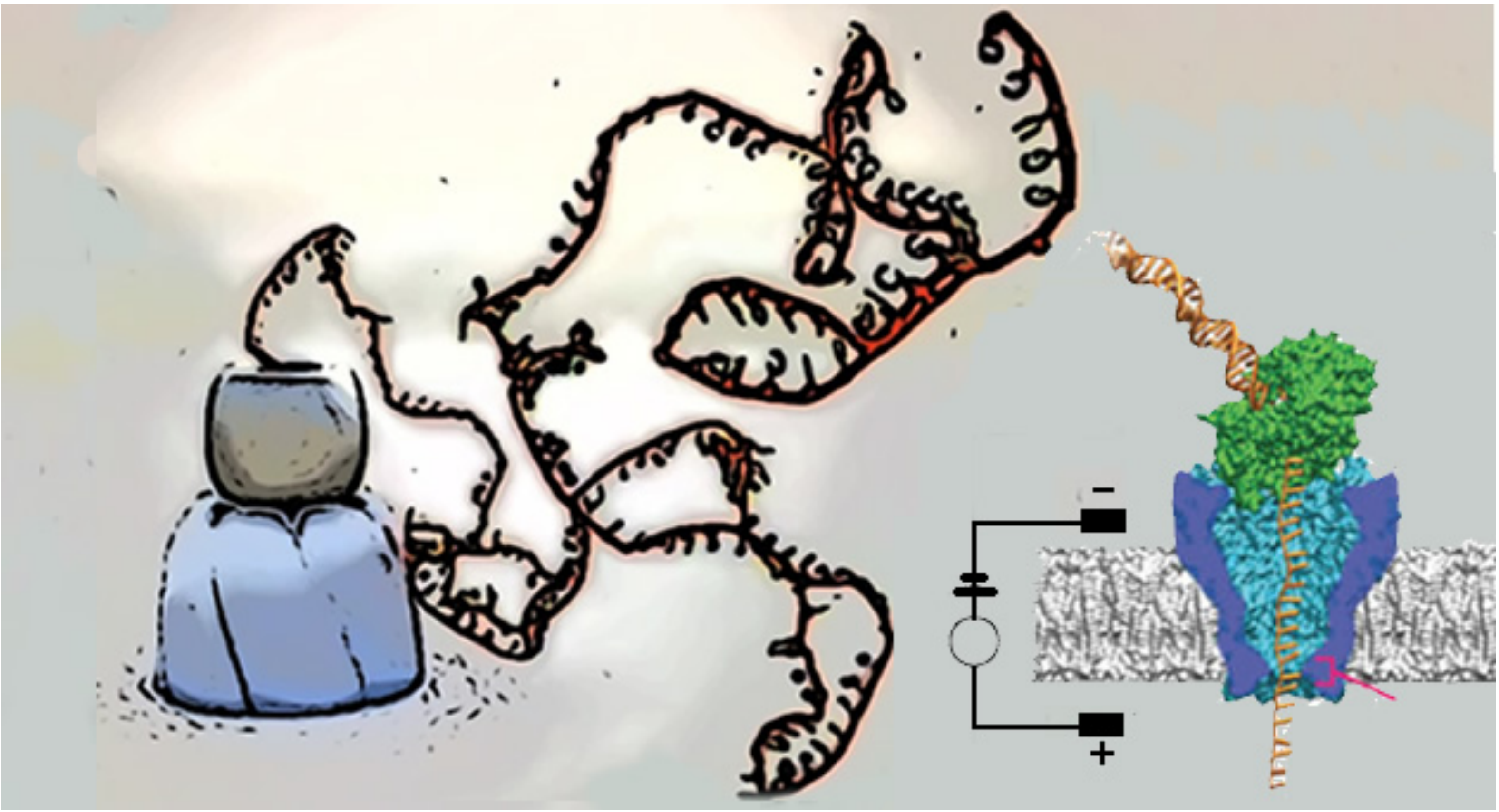
- themes

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

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) ...

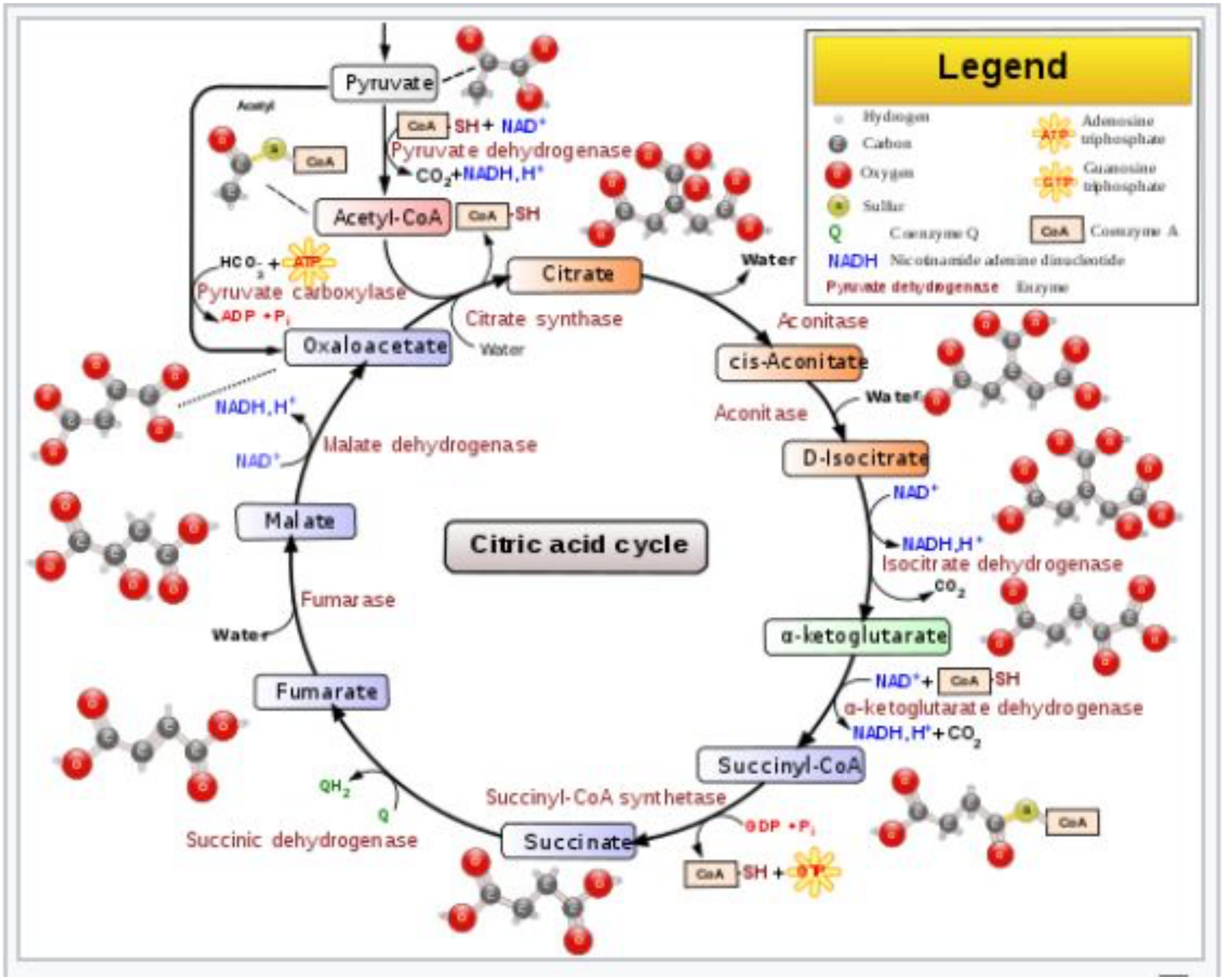


- biological systems are not intelligently designed.

Rube Goldberg

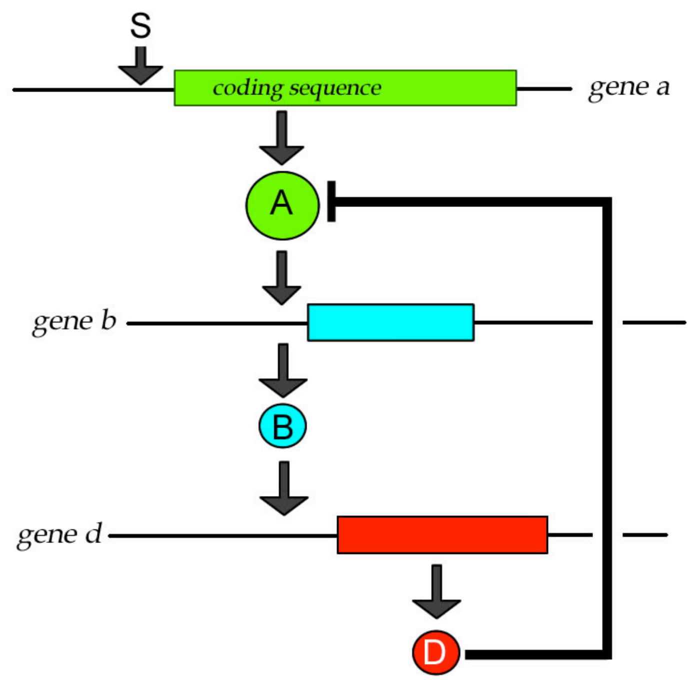
- biological systems are based on systems of coupled chemical reactions.

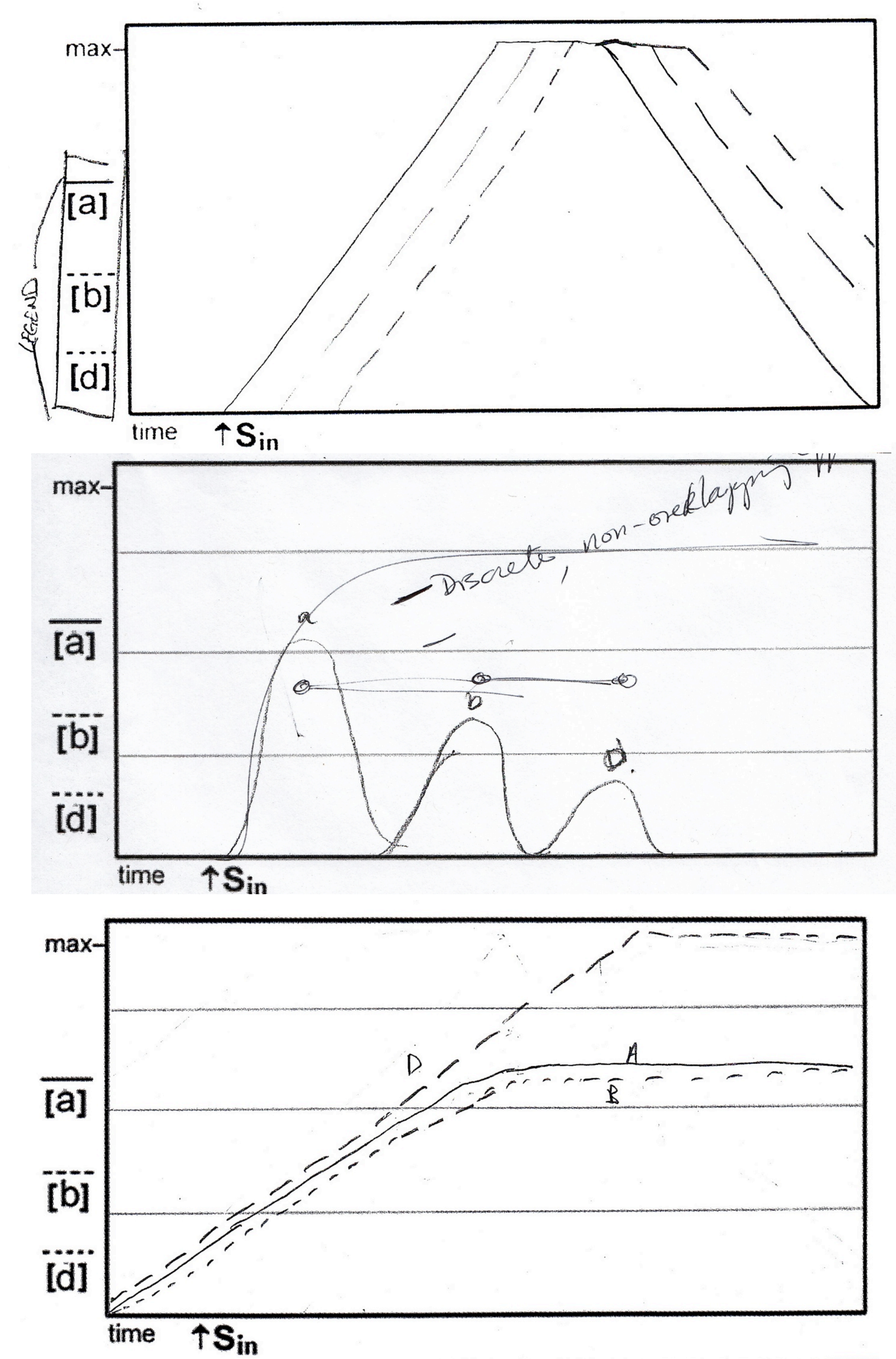
- what is important, conceptually, is the **ubiquity of coupled reaction**, rather than specific reactions



- students can have issues thinking quantitatively.

Generate a graph that displays the behavior of the system; state explicitly your assumptions.





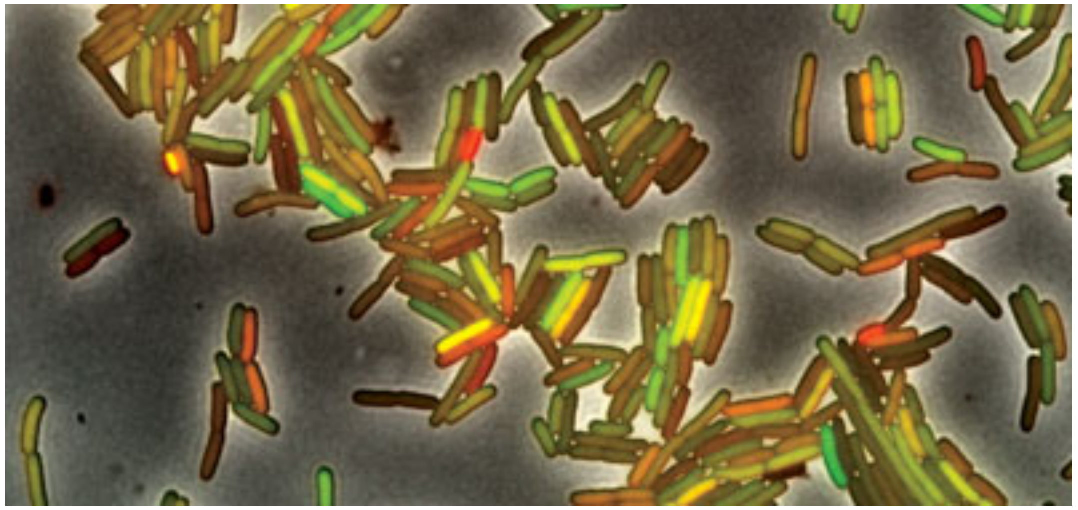
Using Graph-based Assessments Within Socratic Tutorials to Reveal and Refine Students' Analytical Thinking About Molecular Networks*[S]*

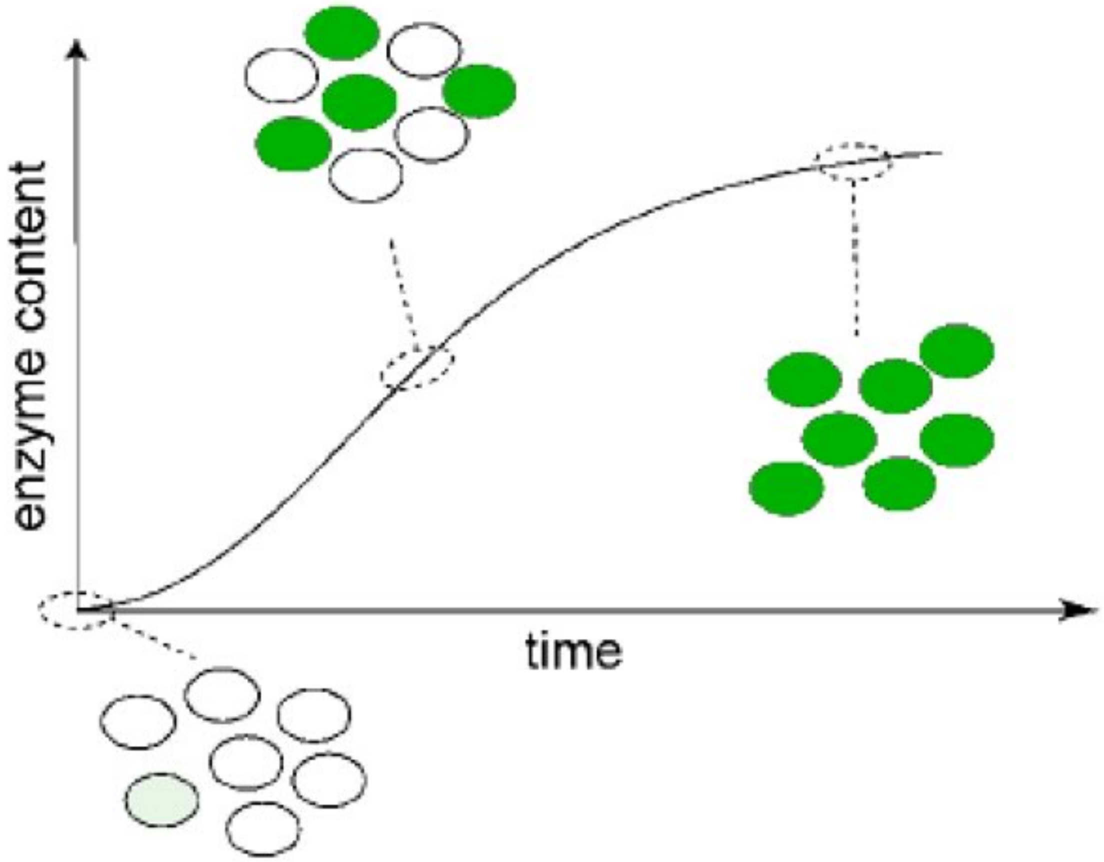
Received for publication, August 6, 2011, and in revised form, November 10, 2011

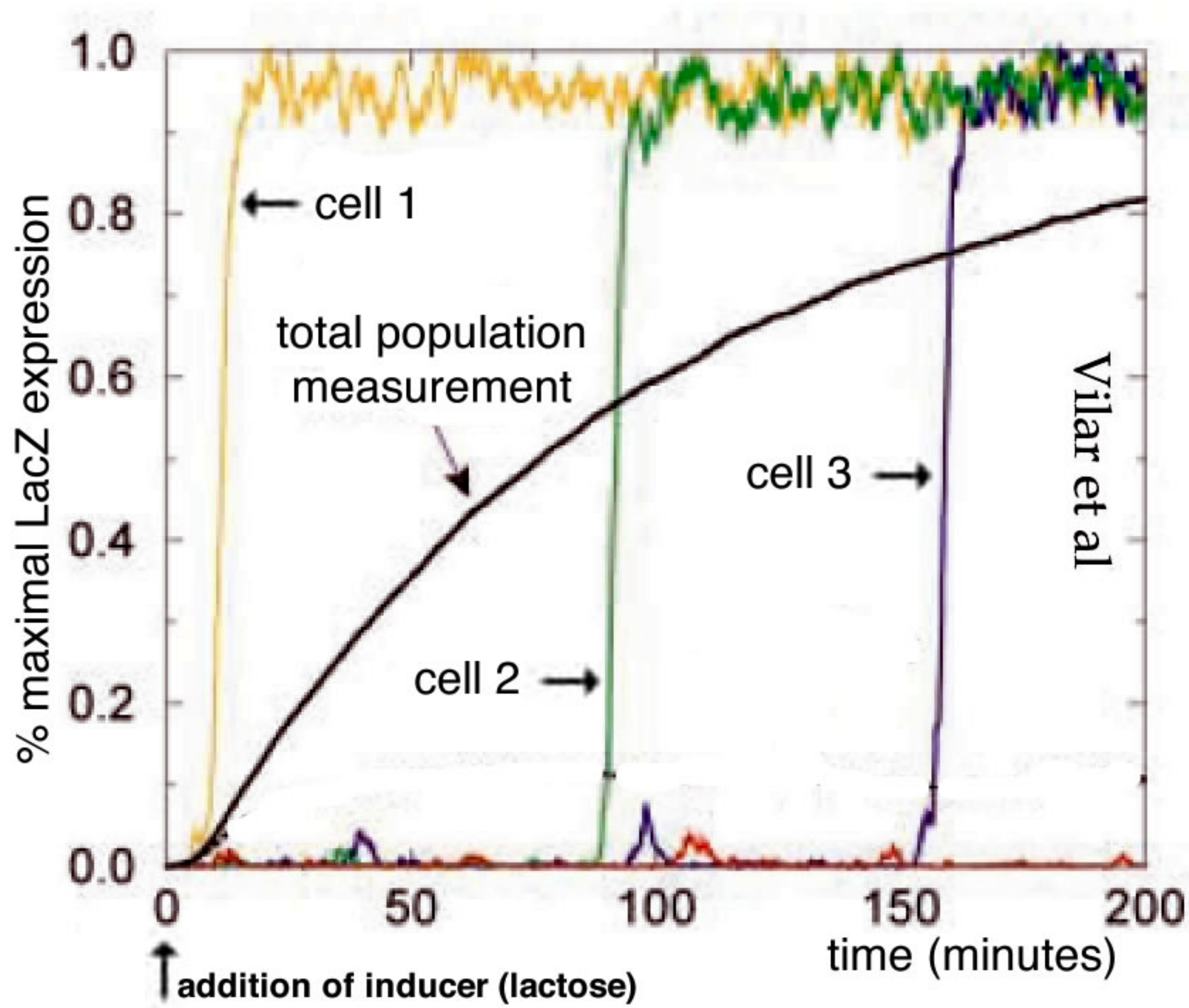
Caleb Trujillo‡, Melanie M. Cooper§, and Michael W. Klymkowsky‡,¶

revealing student thinking

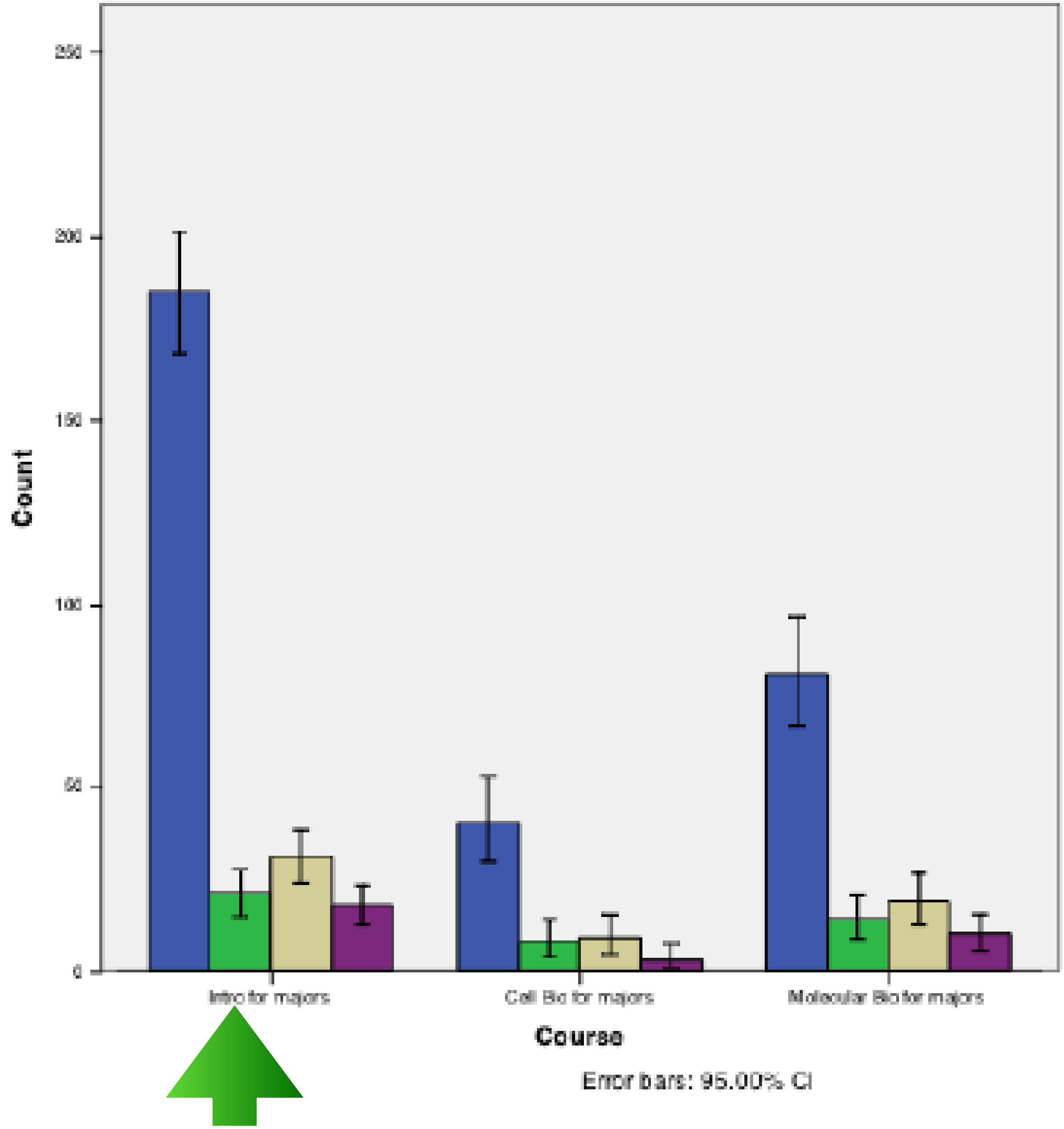
• biological systems are inherently stochastic.







- students often do not "get" the role of stochastics in system behavior.



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

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†

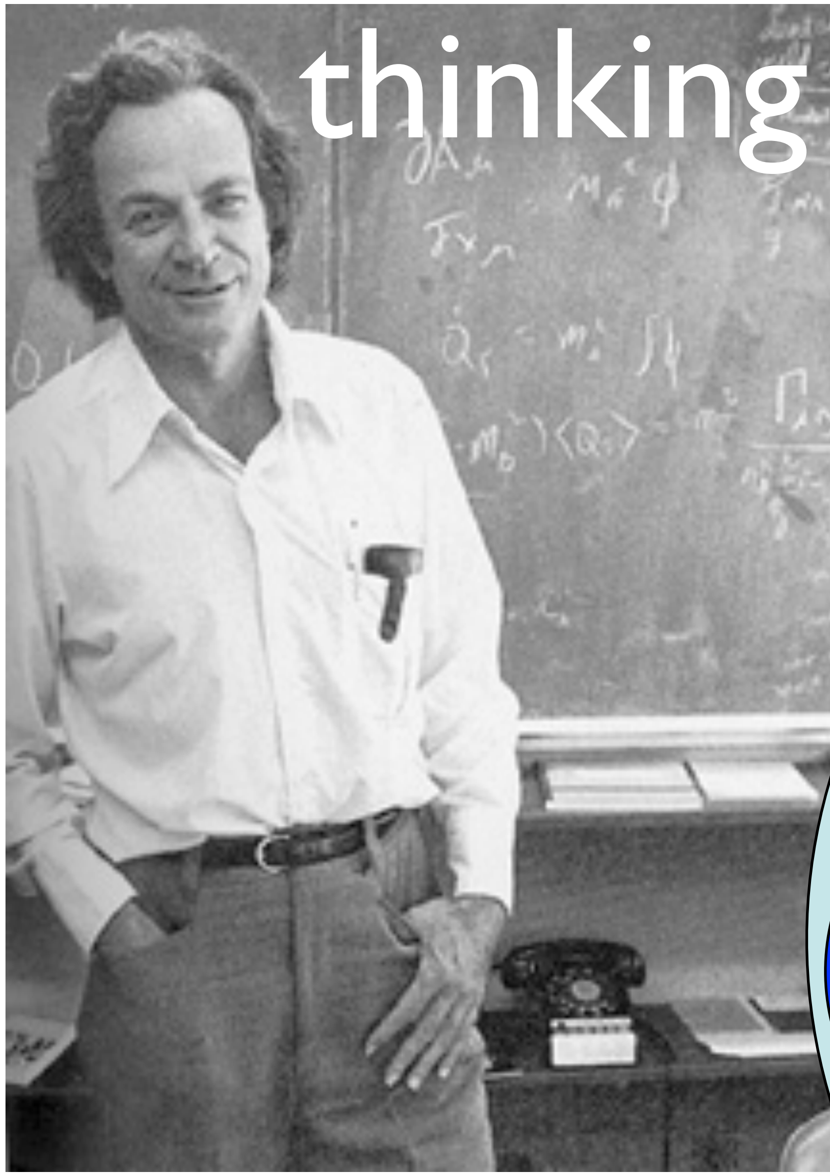
*Center for Integrated Plasma Studies and †Molecular, Cellular, and Developmental Biology Department, University of Colorado, Boulder, CO 80309

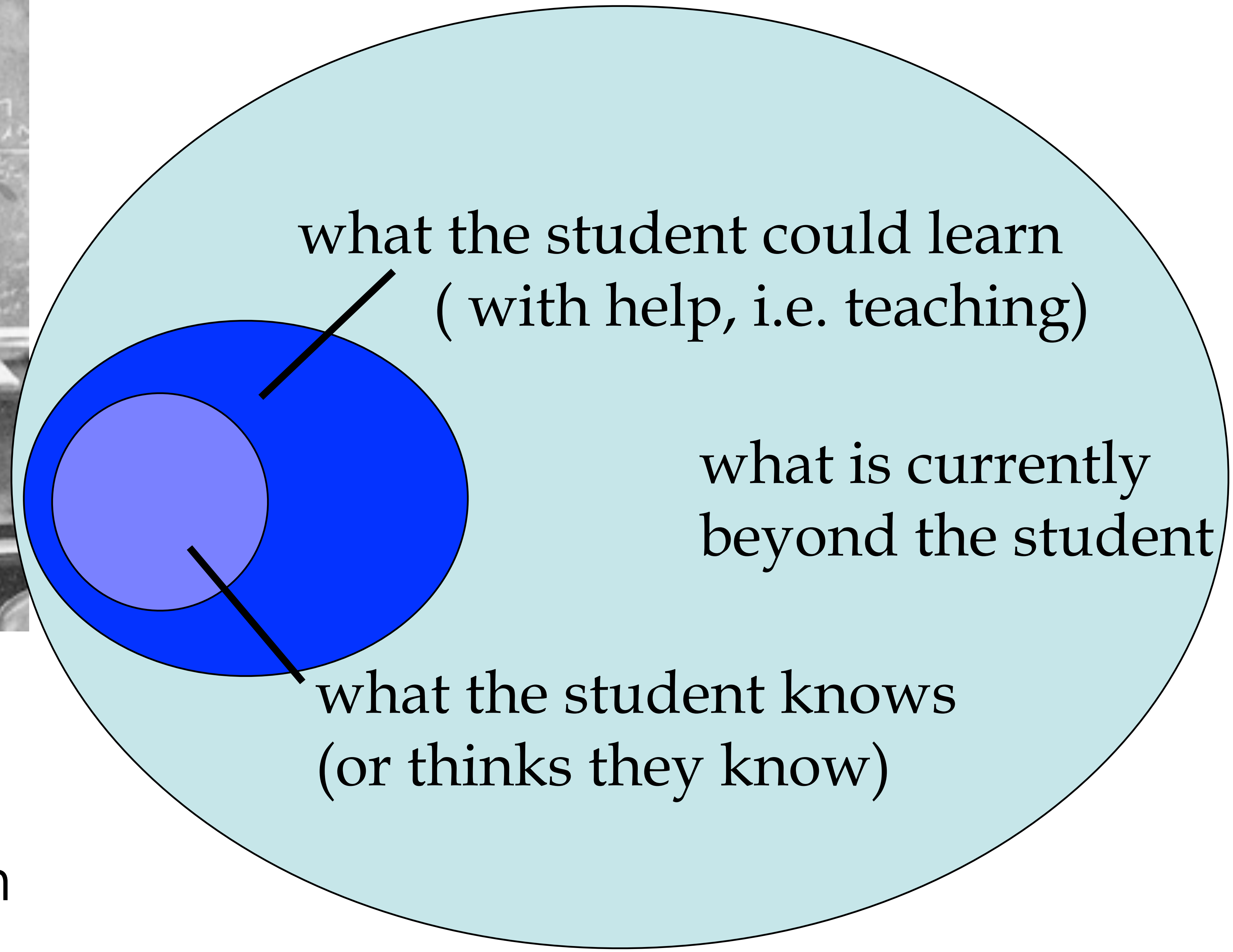
Submitted August 23, 2007; Revised January 14, 2008; Accepted February 7, 2008
Monitoring Editor: Bruce Alberts

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

stochasticity

thinking about magnets





- being explicit about where ideas come from

Vygotsky, L.S. (1978). *Mind and society: The development of higher psychological processes*. Harvard University Pres

Chapters

biofundamentals

1: 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 directly from us.

Different types of questions asked

- Why are non-linear responses to a stimuli important in biological systems? How is it achieved?
  - How would the lac operon behave at different concentrations of lac repressor?
  - How it might it impact the social behavior of slime molds if the percentage of spore cells were 1% rather than 80%?
- **Constructing and testing scenarios** (inspired by Manu Kapur, ETH Zurich)
  - Devise as many mechanisms as you can by which organisms could distinguish self from non-self?
    - How might you test which of your mechanisms is active in a particular organism?

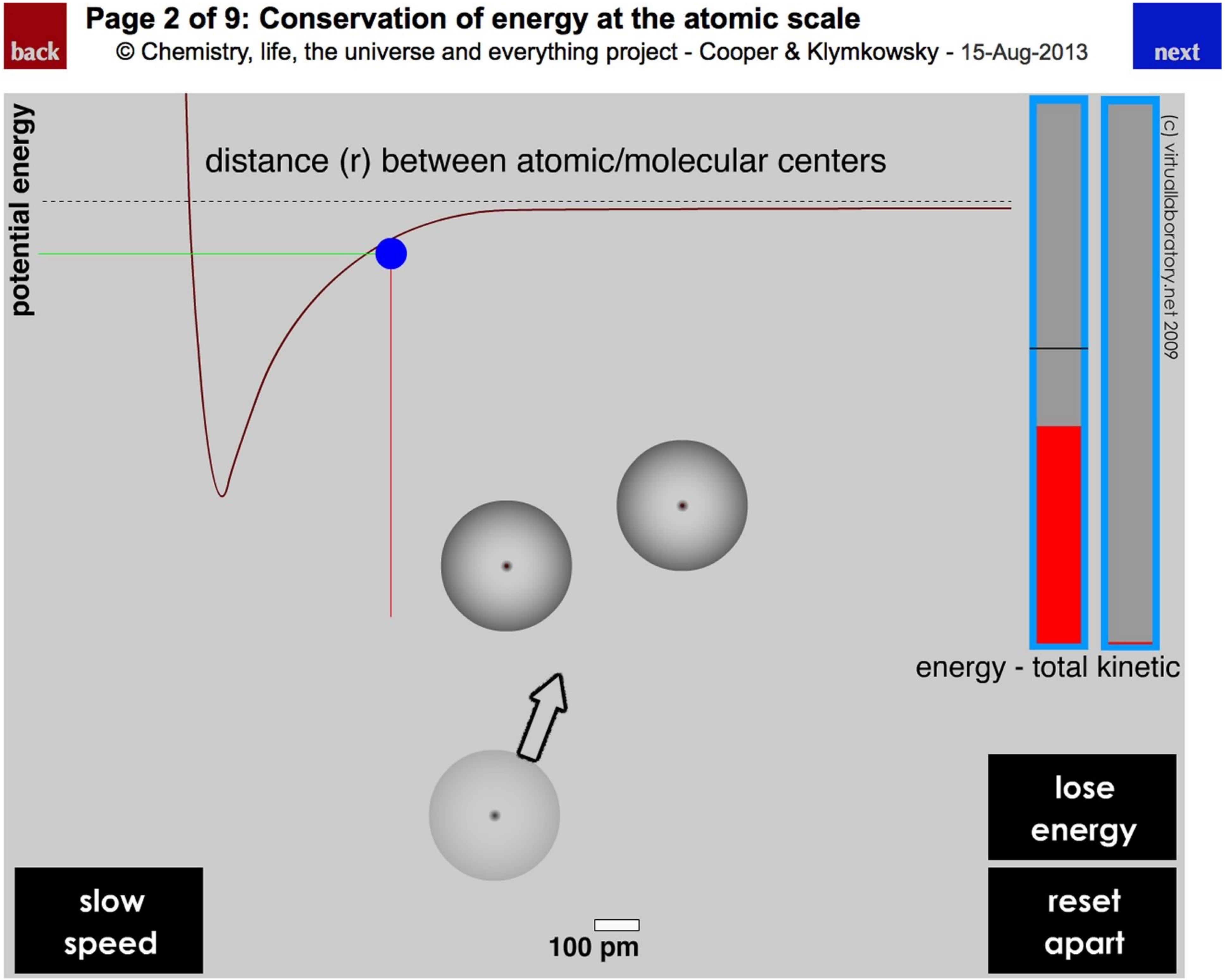
CLUE
CHEMISTRY, LIFE, THE UNIVERSE
& EVERYTHING

CLUE
ORGANIC CHEMISTRY
LIFE, THE UNIVERSE **& EVERYTHING**

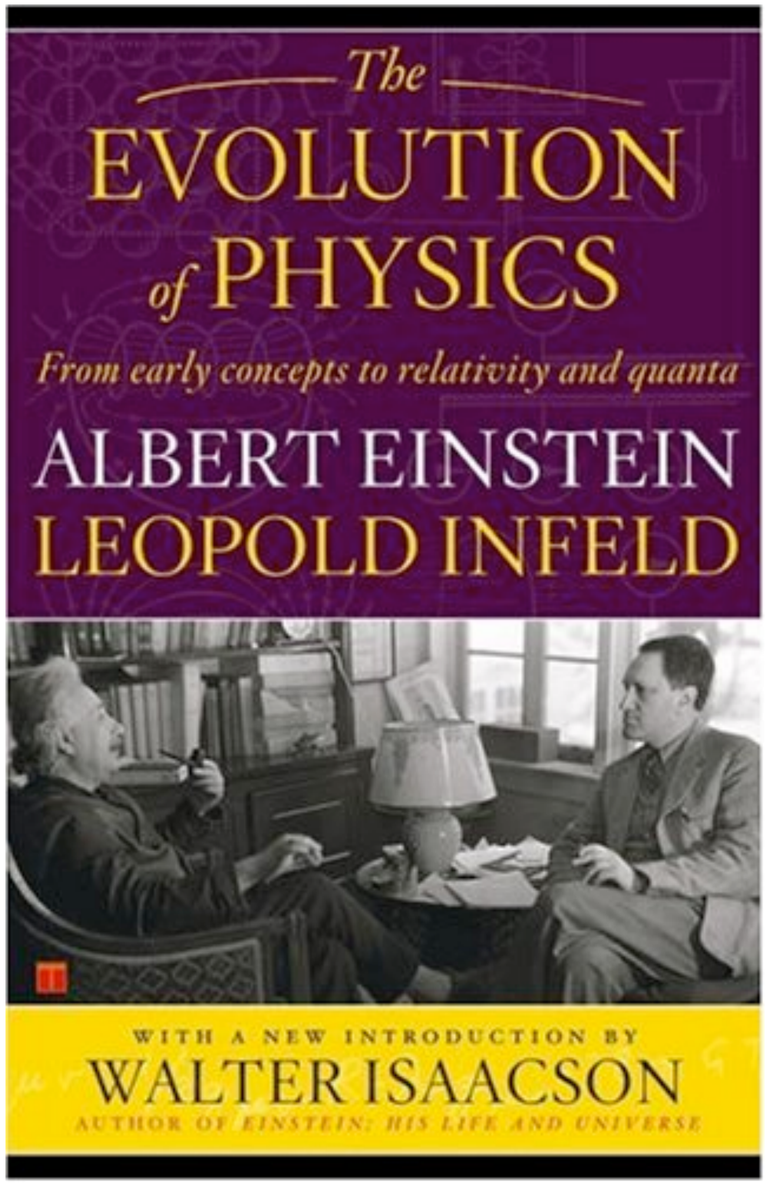
engineering more effective courses: CLUE

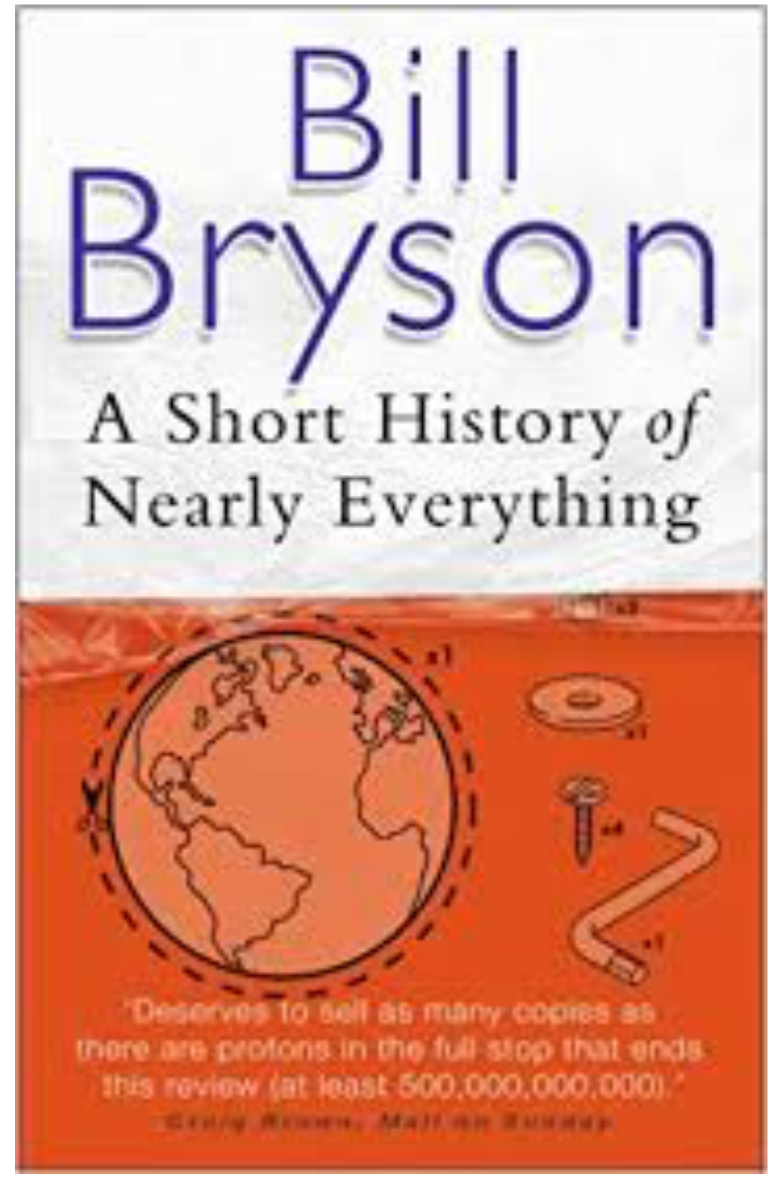
Catalyst for CLUE

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

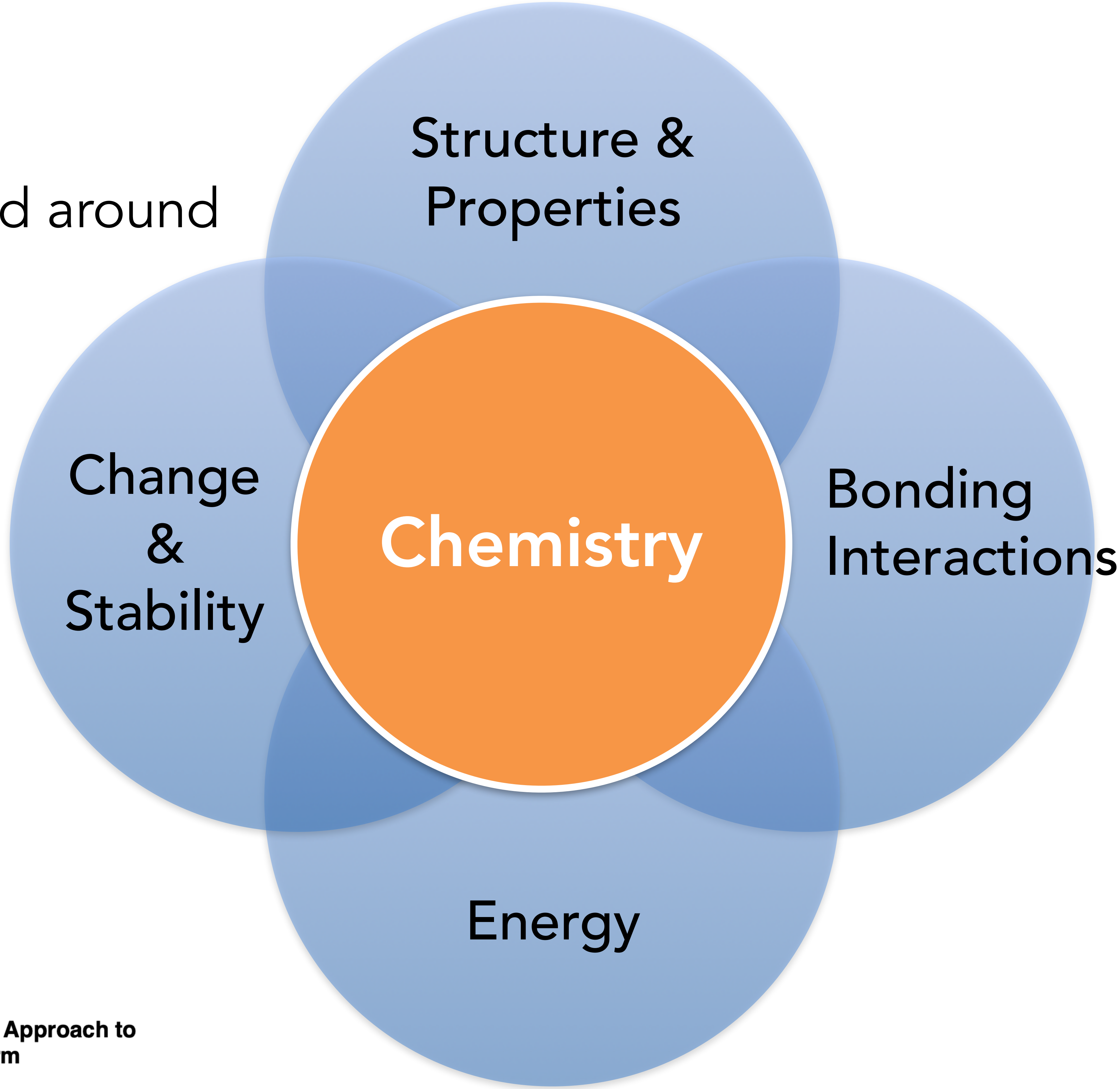


Writing style (minimal figures) – narrative framework for materials presented – practice through beSocratic and in class activities





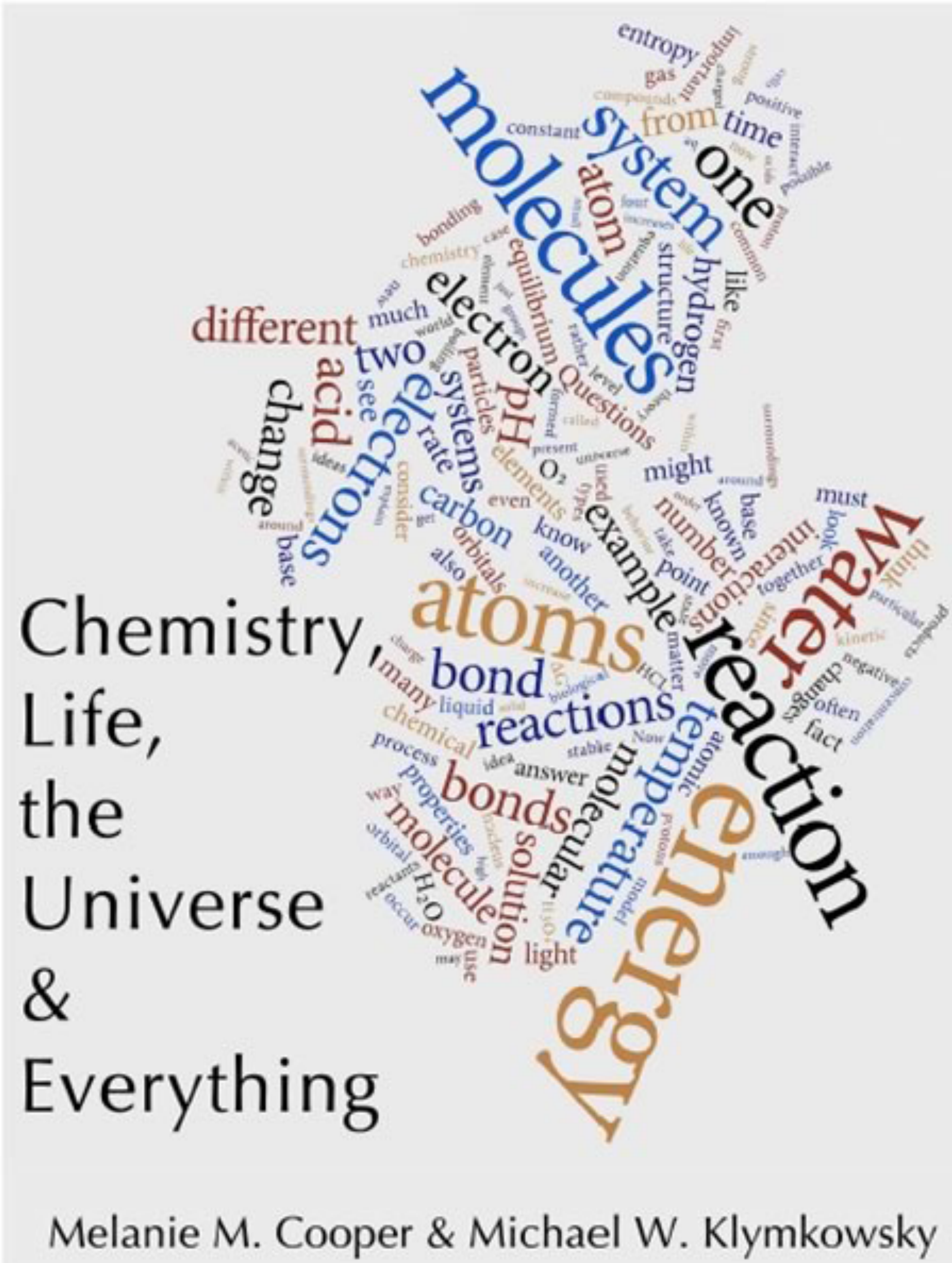
Focused around



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

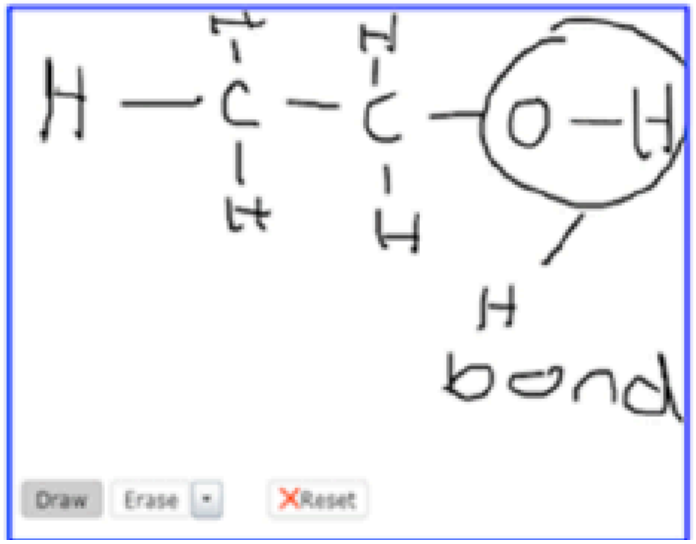
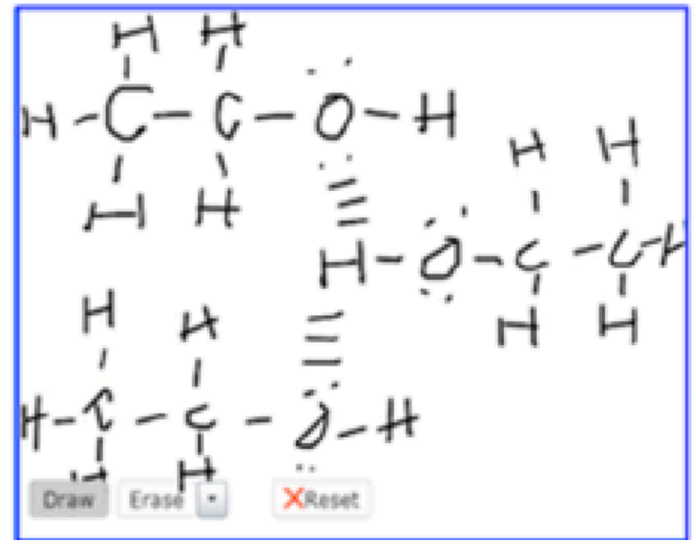
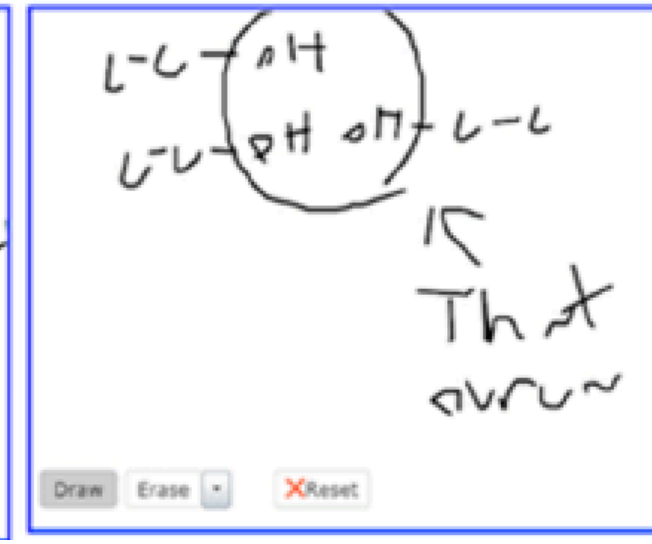
Melanie Cooper*† and Michael Klymkowsky‡
† Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, United States
‡ Molecular, Cellular and Developmental Biology and CU Teach, University of Colorado, Boulder, Colorado 80309, United States

engineering more effective courses: CLUE

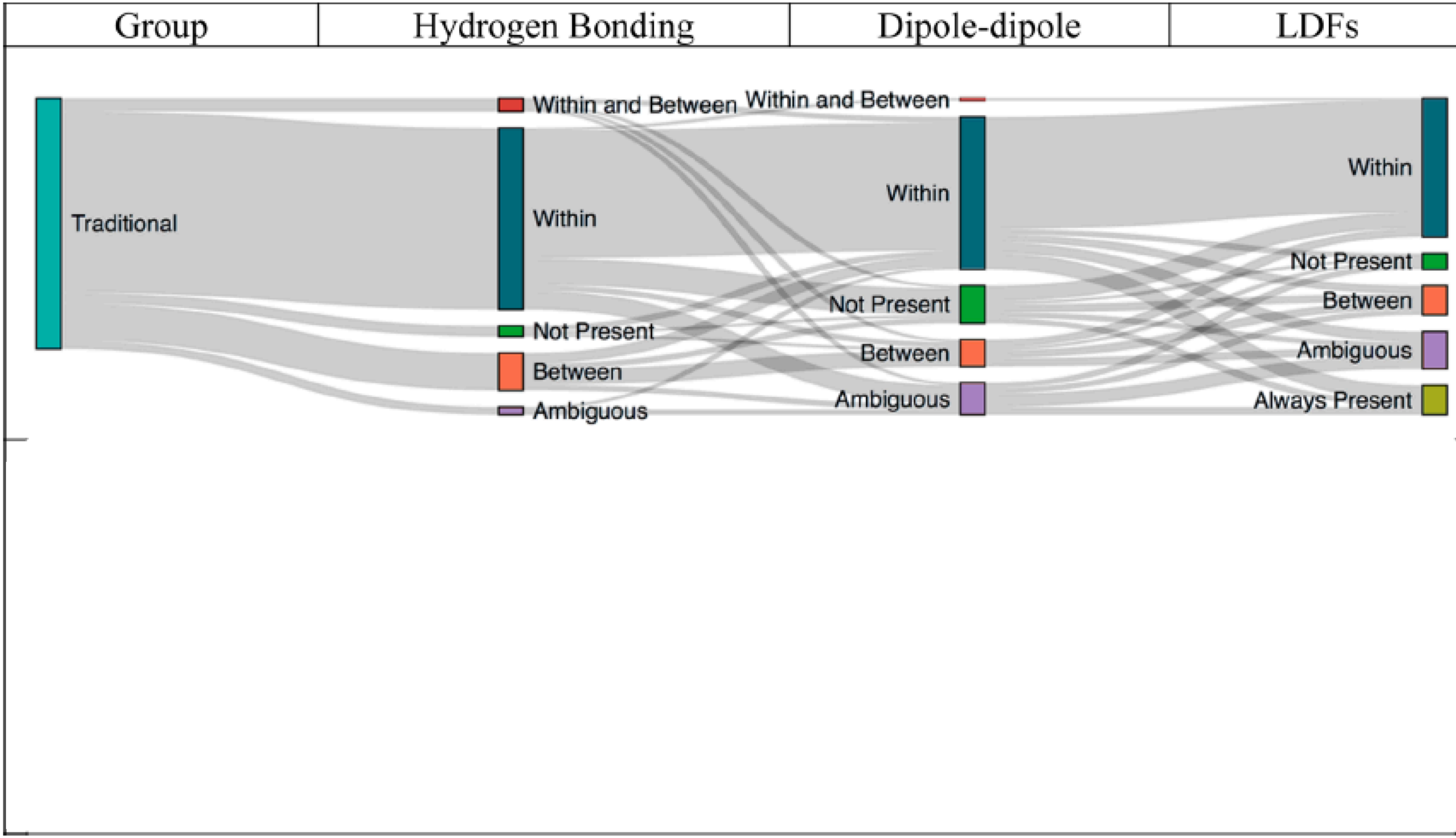


1. Atoms
2. Electrons & orbitals
3. Elements, bonding
4. Heterogenous compounds
5. Systems thinking
6. Solutions
7. Chemical reactions
8. How far? how fast
9. Reaction systems

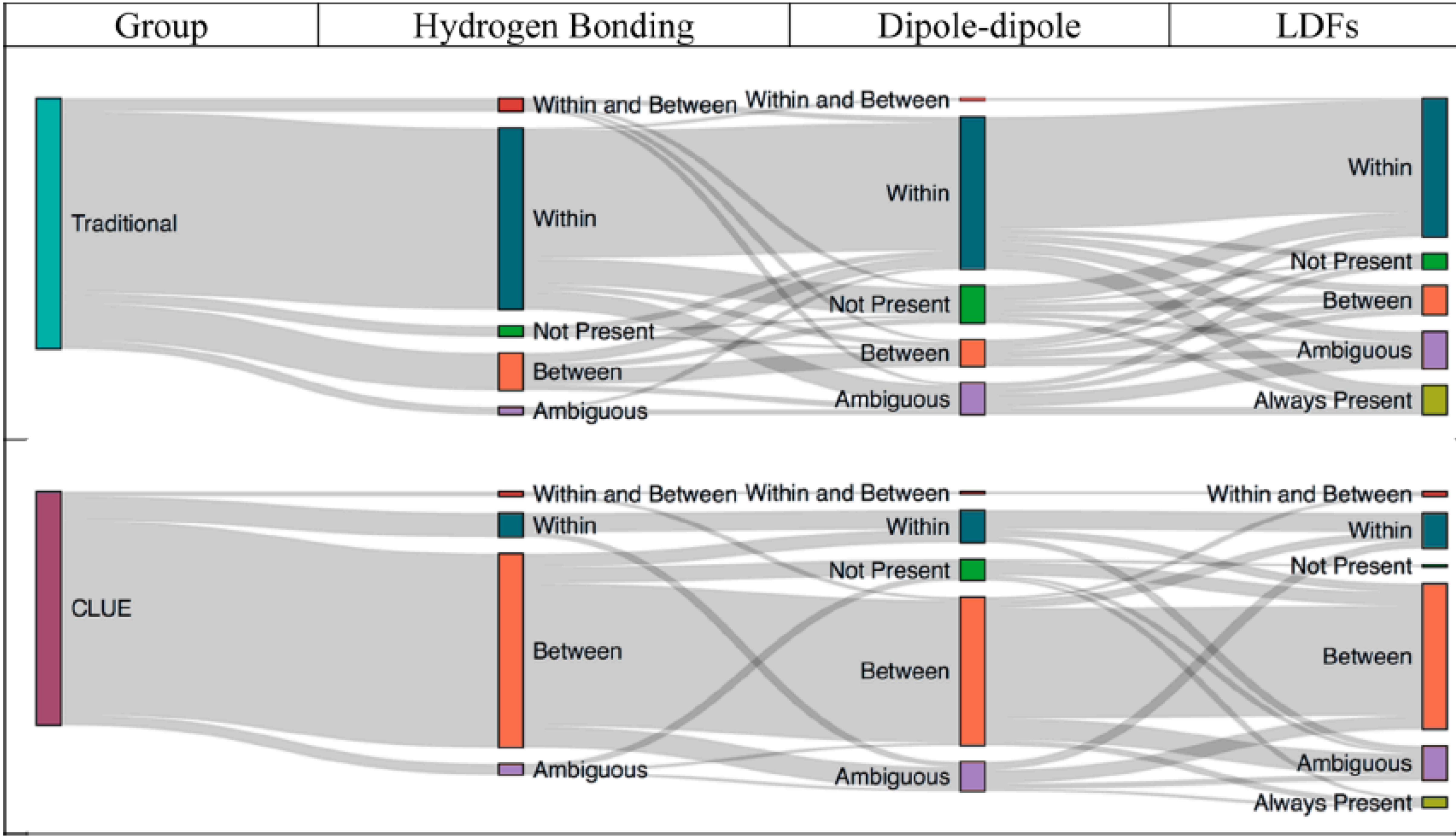
Types of analyses possible through beSocratic: intermolecular interactions

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

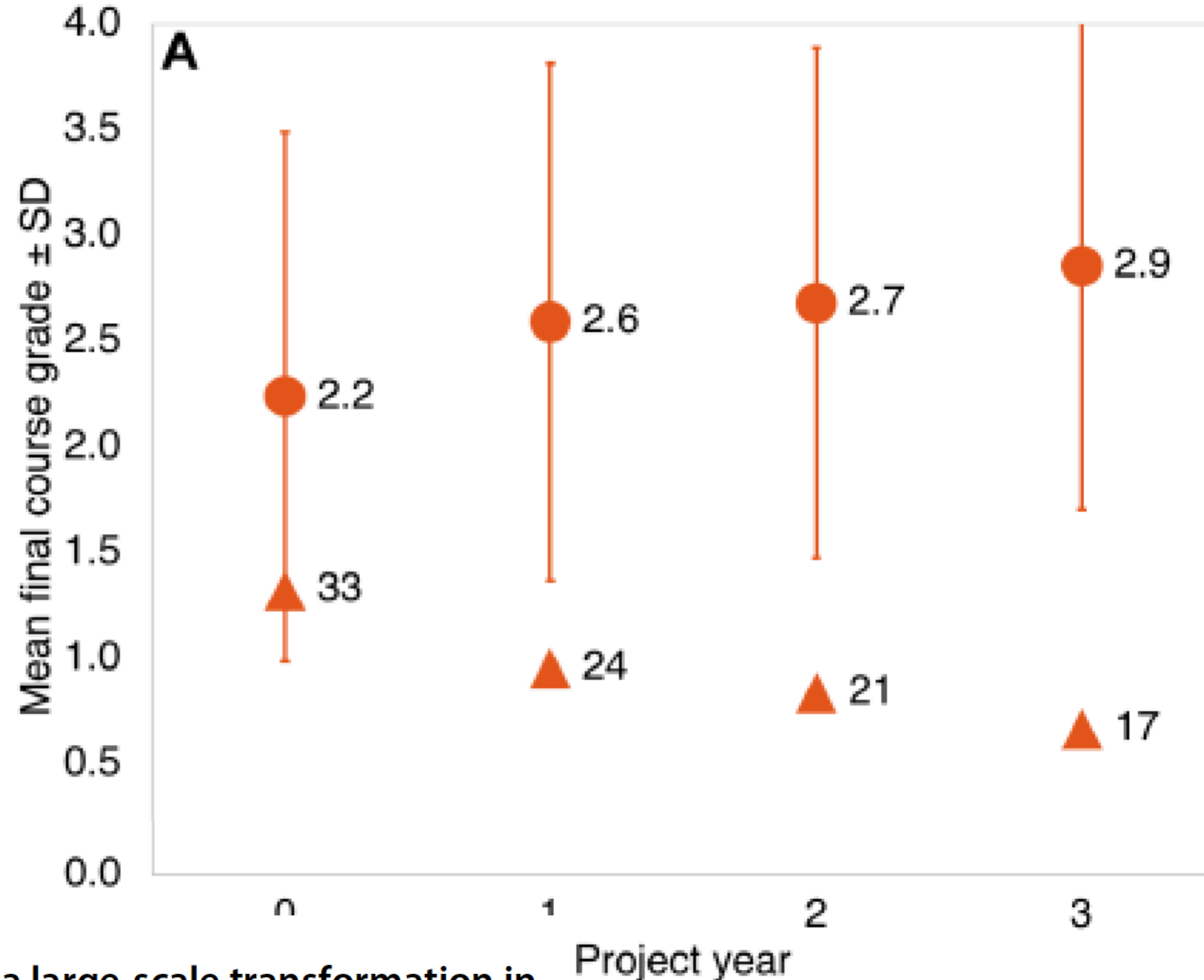
Type analysis possible through beSocratic: intermolecular interactions



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.

From

CLUE

CHEMISTRY, LIFE, THE UNIVERSE
& EVERYTHING

to

OCLUE

ORGANIC CHEMISTRY
LIFE, THE UNIVERSE **& EVERYTHING**

Cooper, Stowe, Crandell & Klymkowsky, M. *J. Chem. Educ.* submitted

OCLUE
ORGANIC CHEMISTRY
LIFE, THE UNIVERSE & EVERYTHING

Design

The Theoretical principles → The Vision → The Compromises → The Enactment → The Evidence

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

OCLUE
ORGANIC CHEMISTRY
LIFE, THE UNIVERSE & EVERYTHING

Traditional Organic Chemistry

Participants

Mostly Pre-professional majors
~75% female

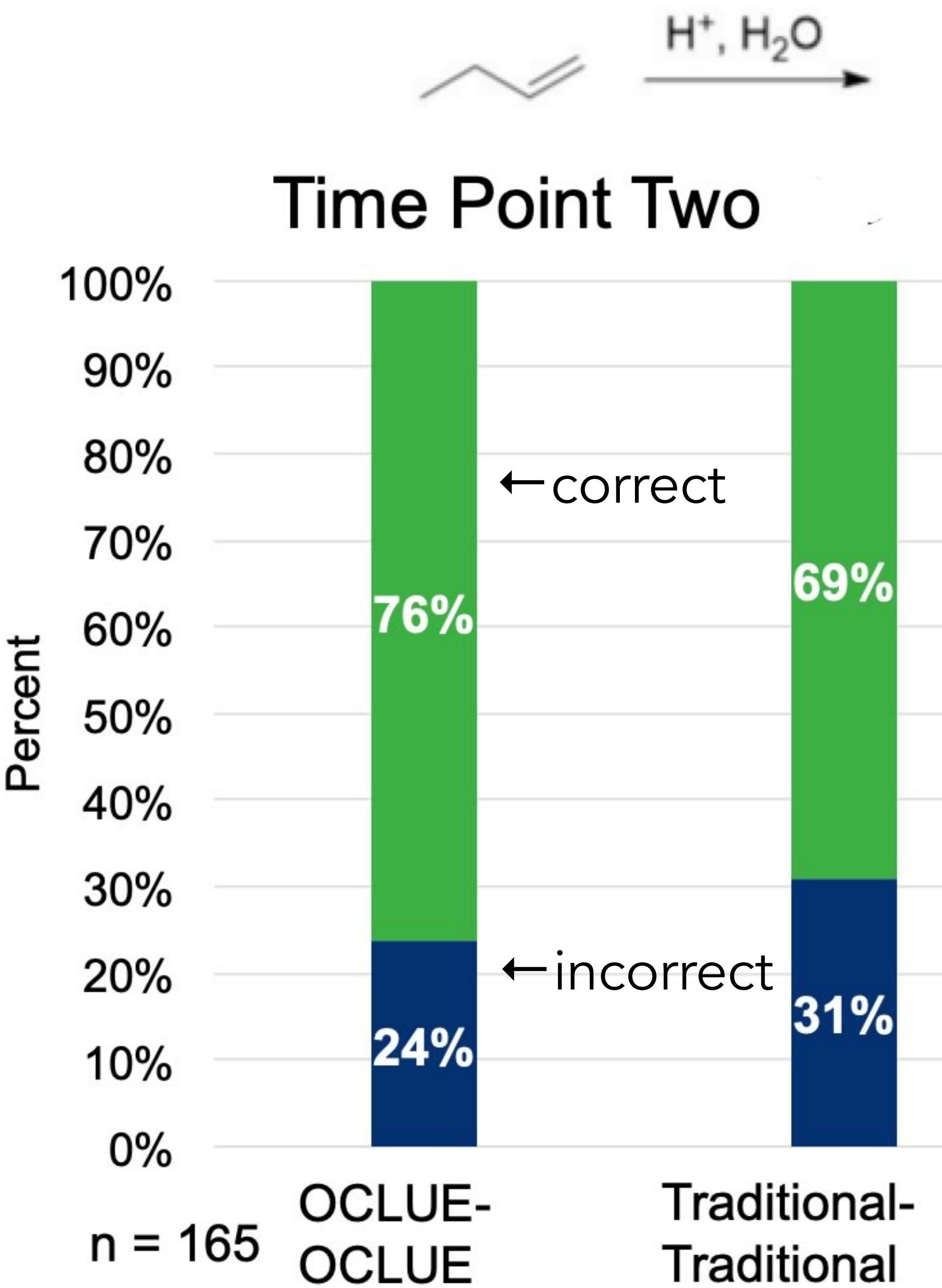
Compared on:
ACT score
GC1 Grade
GC2 Grade
OC1 Grade
OC2 Grade
GPA Prior to OC1

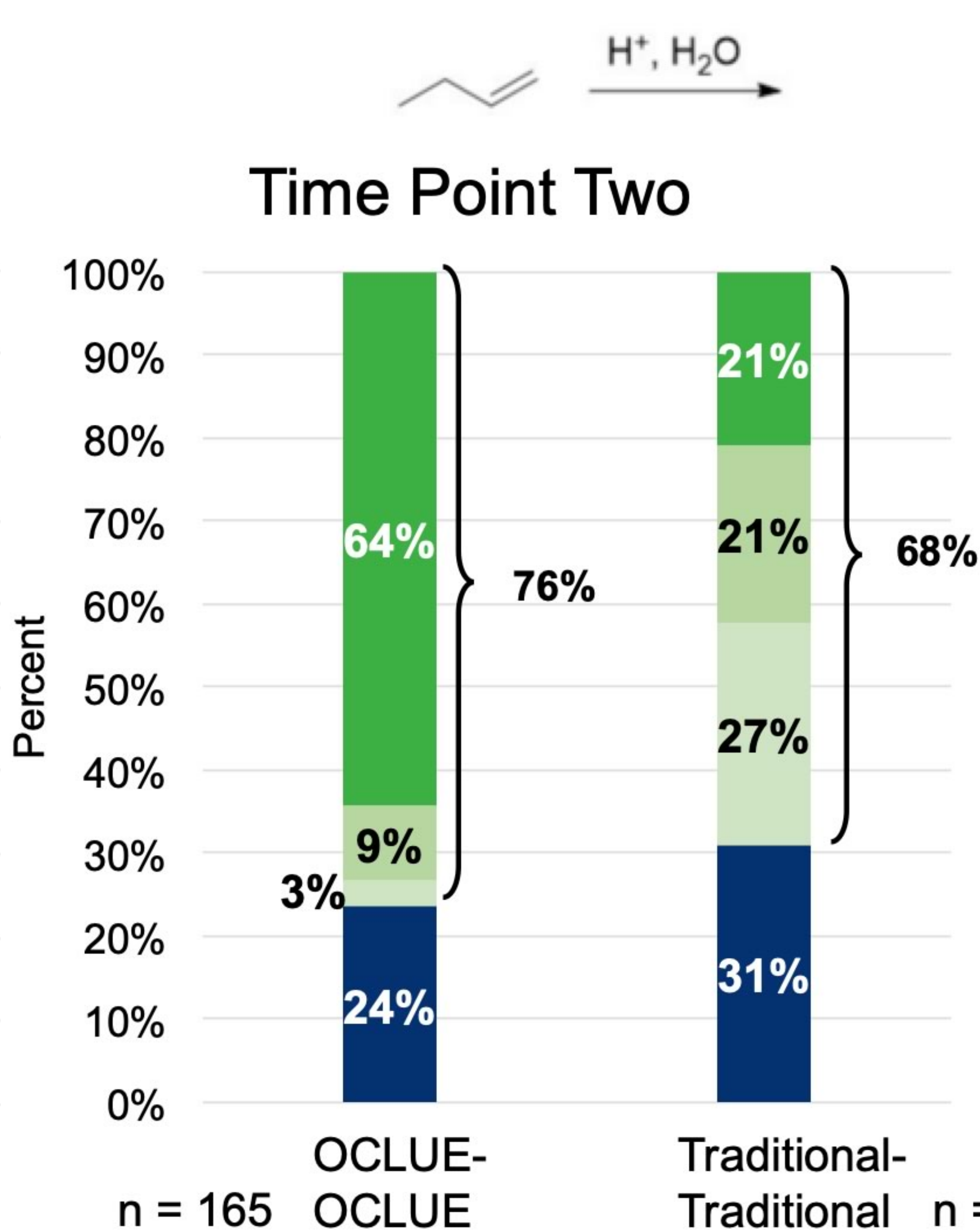
Year 2 Time Point 1

Year 2 Time Point 2

Fall 2016	Spring 2017	Fall 2017	Spring 2018	Fall 2018	Spring 2019
Year 1		Year 2		Year 3	

outcomes data from the Cooper group





All Correct Arrows & Correct Product

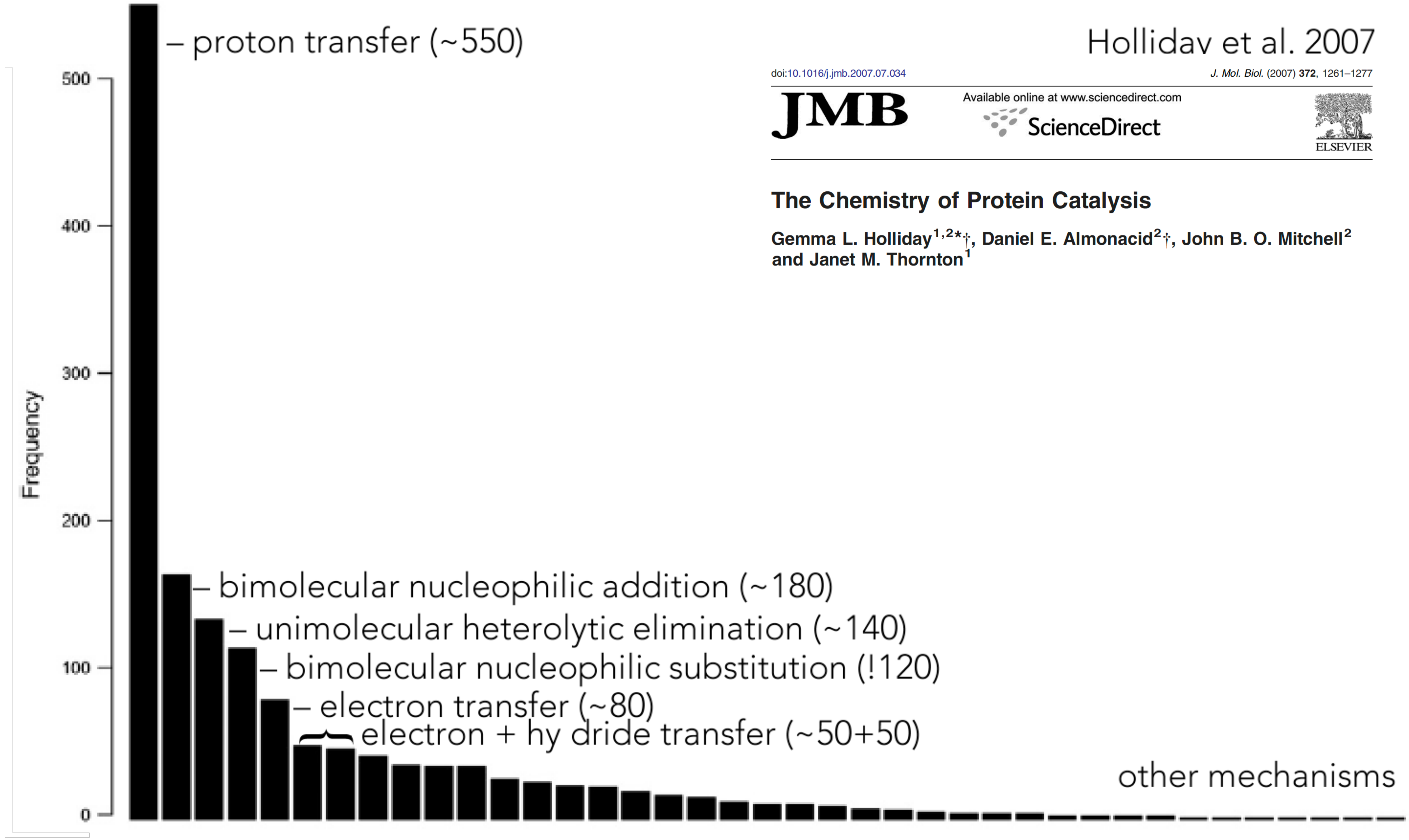
Some Correct Arrows & Correct Product

No Arrows & Correct Product

Mann-Whit U	
p	0.000
r	0.55

Significant different and large effect size

Holliday et al. 2007



doi:10.1016/j.jmb.2007.07.034

J. Mol. Biol. (2007) 372, 1261–1277

JMB

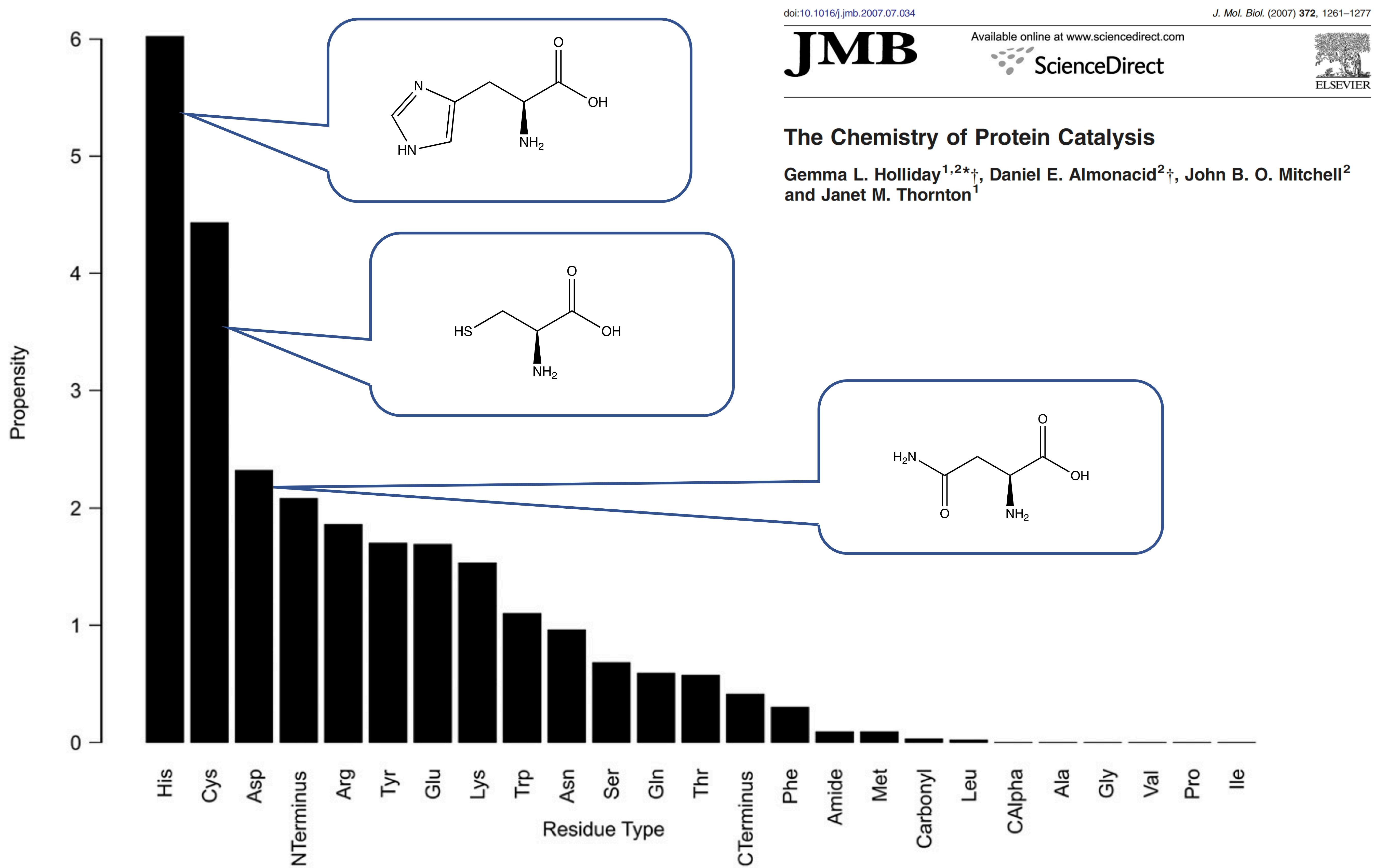
Available online at www.sciencedirect.com

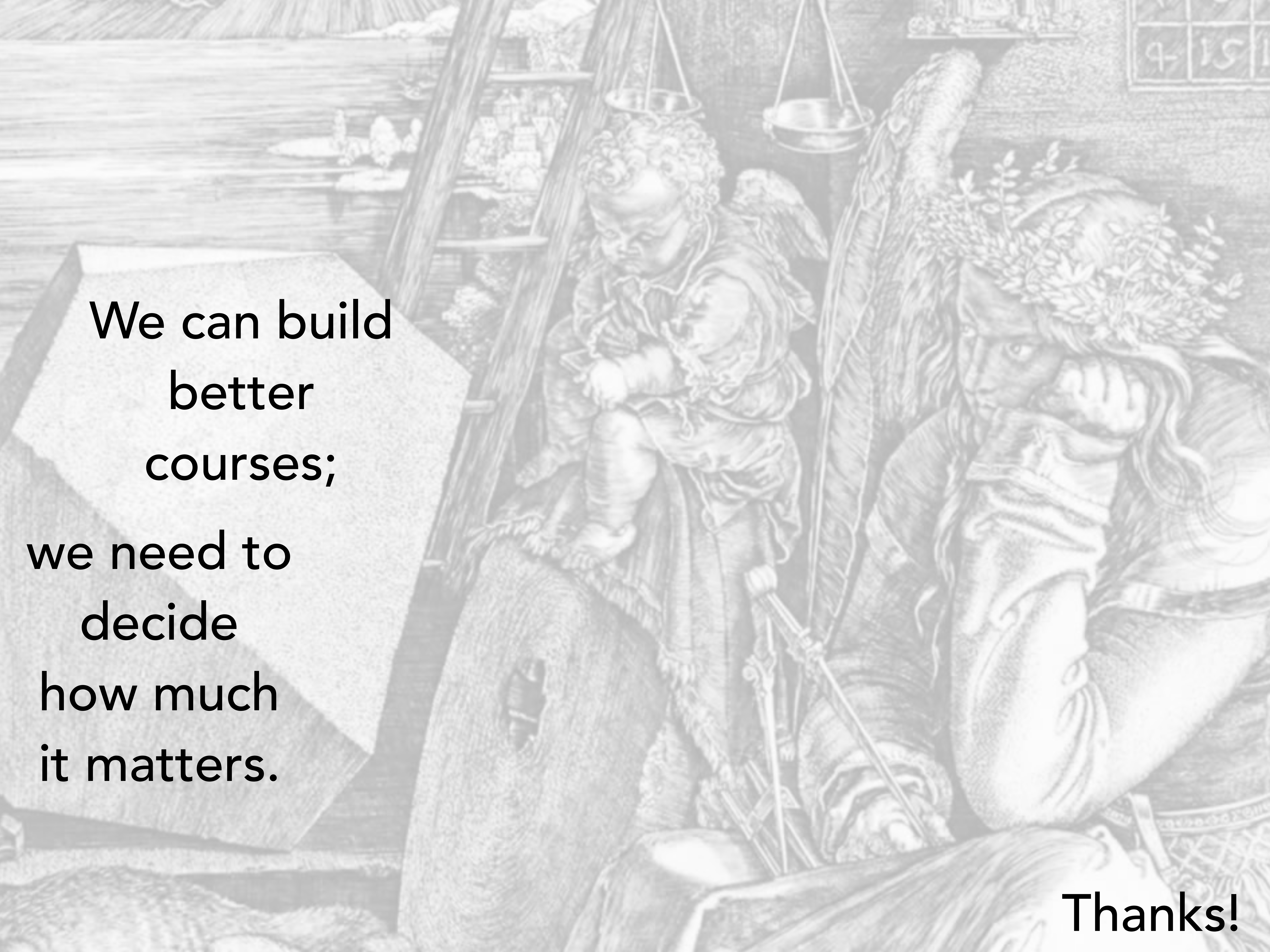
ScienceDirect

ELSEVIER

The Chemistry of Protein Catalysis

Gemma L. Holliday[1,2*†], Daniel E. Almonacid[2†], John B. O. Mitchell[2] and Janet M. Thornton[1]


doi:10.1016/j.jmb.2007.07.034
J. Mol. Biol. (2007) 372, 1261–1277
JMB
Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
The Chemistry of Protein Catalysis
Gemma L. Holliday[1,2*†], Daniel E. Almonacid[2†], John B. O. Mitchell[2] and Janet M. Thornton[1]
Propensity
0
1
2
3
4
5
6
Residue Type
His
Cys
Asp
NTerminus
Arg
Tyr
Glu
Lys
Trp
Asn
Ser
Gln
Thr
CTerminus
Phe
Amide
Met
Carbonyl
Leu
CAlpha
Ala
Gly
Val
Pro
Ile
N
HN
O
OH
NH_2
HS
O
OH
NH_2
H_2N
O
O
OH
NH_2



We can build better courses;

we need to decide how much it matters.

Thanks!