# Towards a coherent & interactive curriculum in the sciences

Mike Klymkowsky
Molecular, Cellular & Developmental Biology / CU Teach

TRUSE II June

Melanie Cooper (Clemson) & the CLUE team

thanks NSF

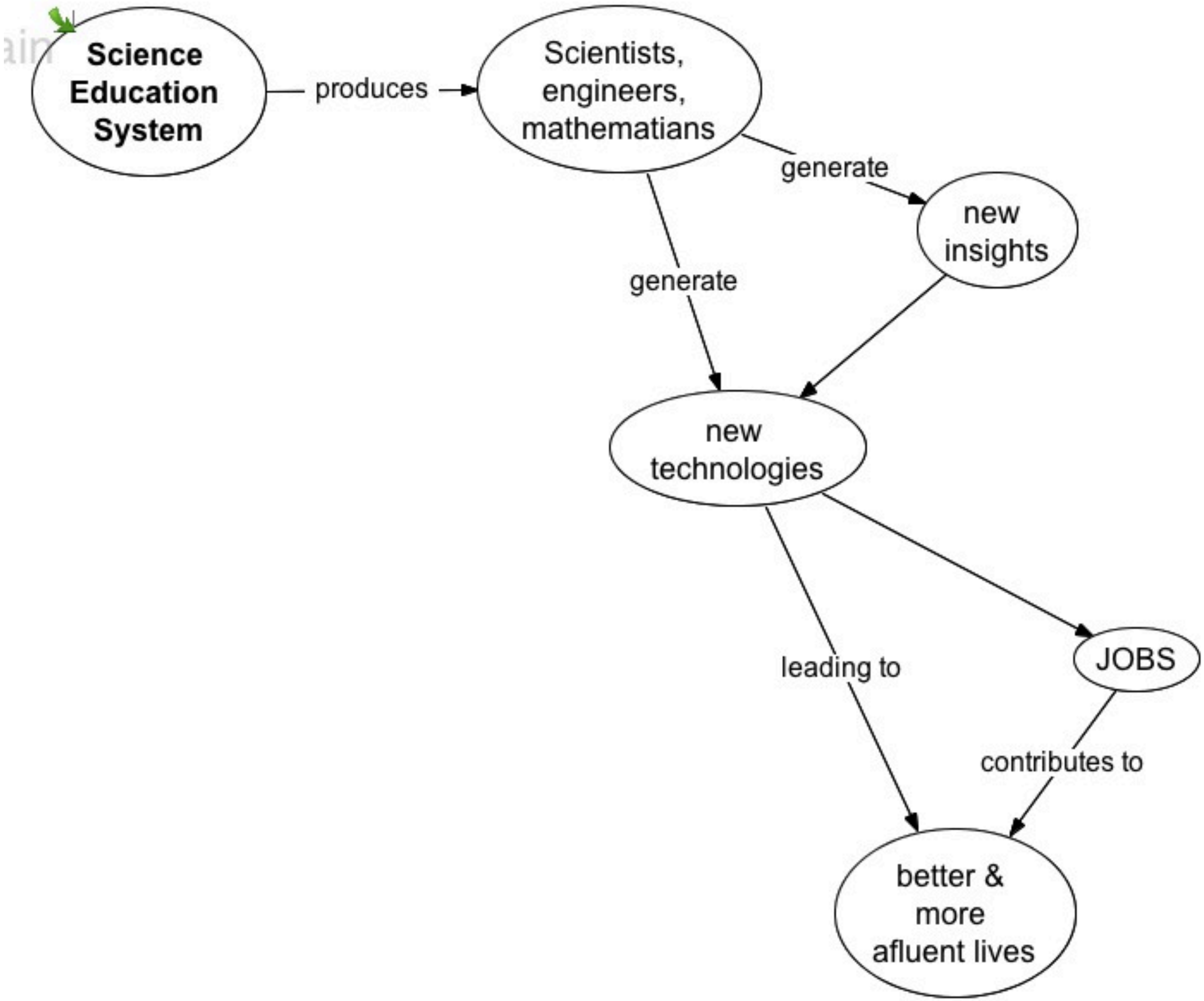
CU Teach
Science & Mathematics

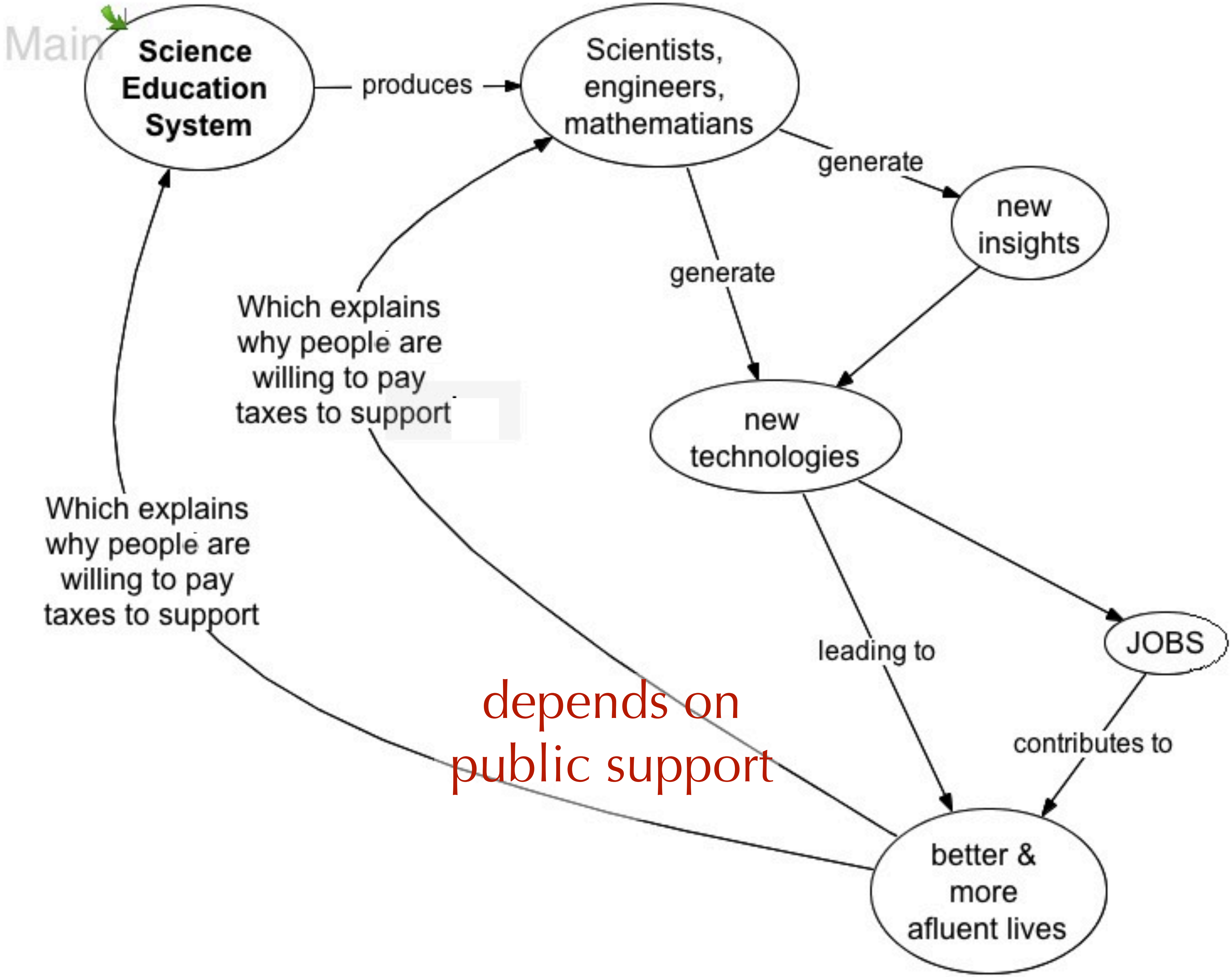
STE&M ER@CU
science, technology, engineering & mathematics education research

*& our students*

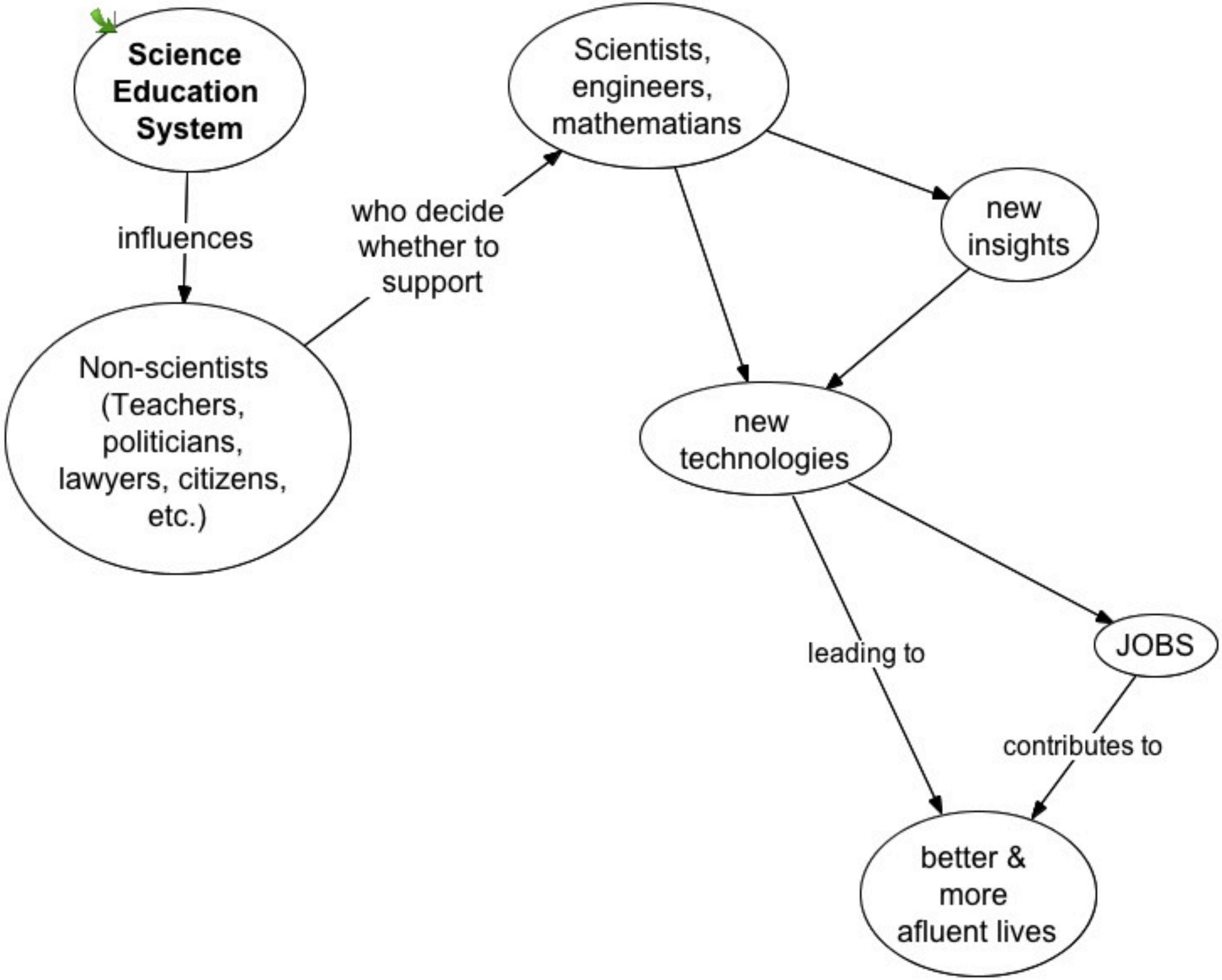

# Who & what is science education for?

# most obviously




Main
Science Education System
produces
Scientists, engineers, mathematians
generate
new insights
generate
new technologies
leading to
JOBS
contributes to
better & more afluent lives
Which explains why people are willing to pay taxes to support
Which explains why people are willing to pay taxes to support
depends on public support


Has effects beyond the generation of scientists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influences
Non-scientists (Teachers, politicians, lawyers, citizens, etc.)
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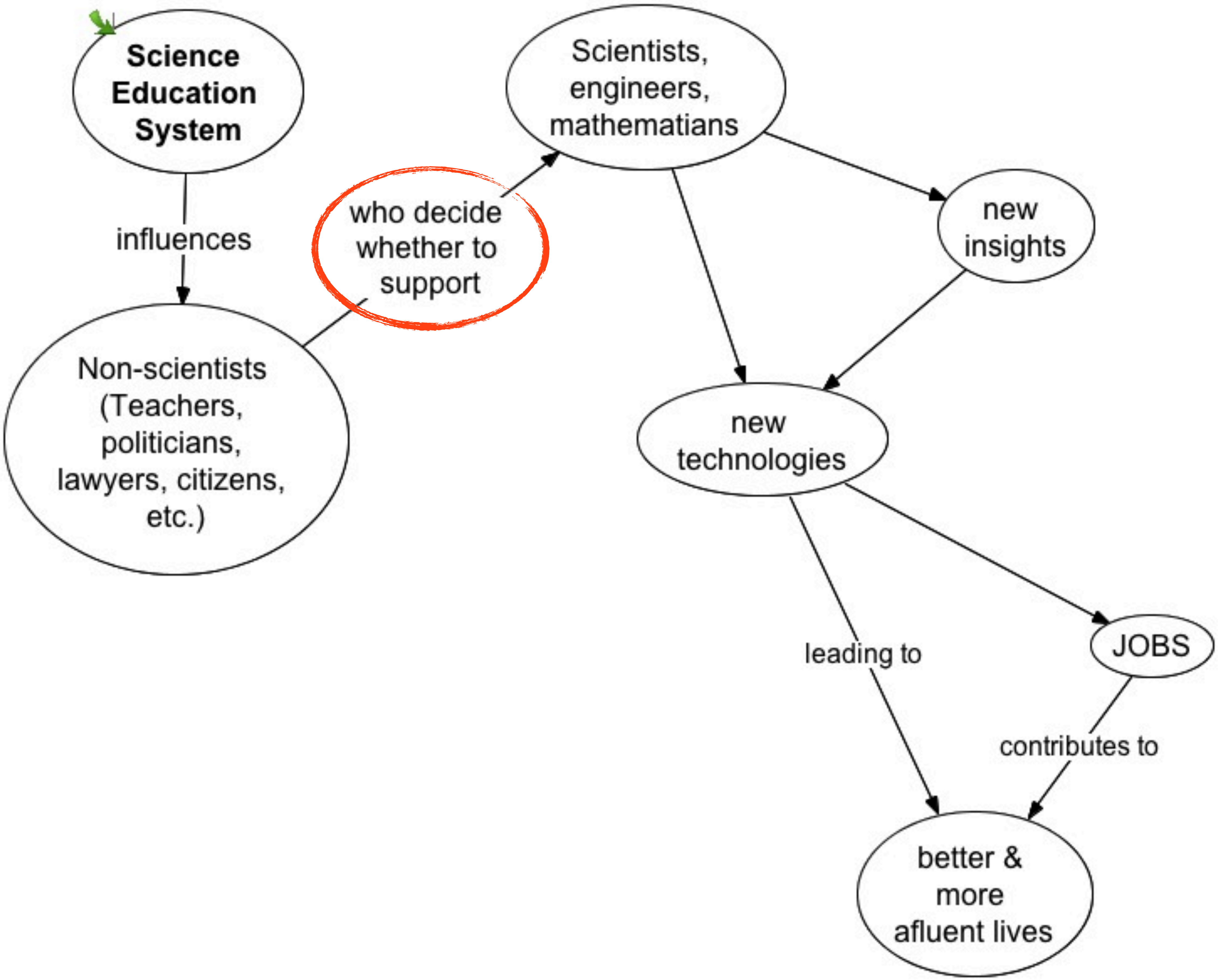

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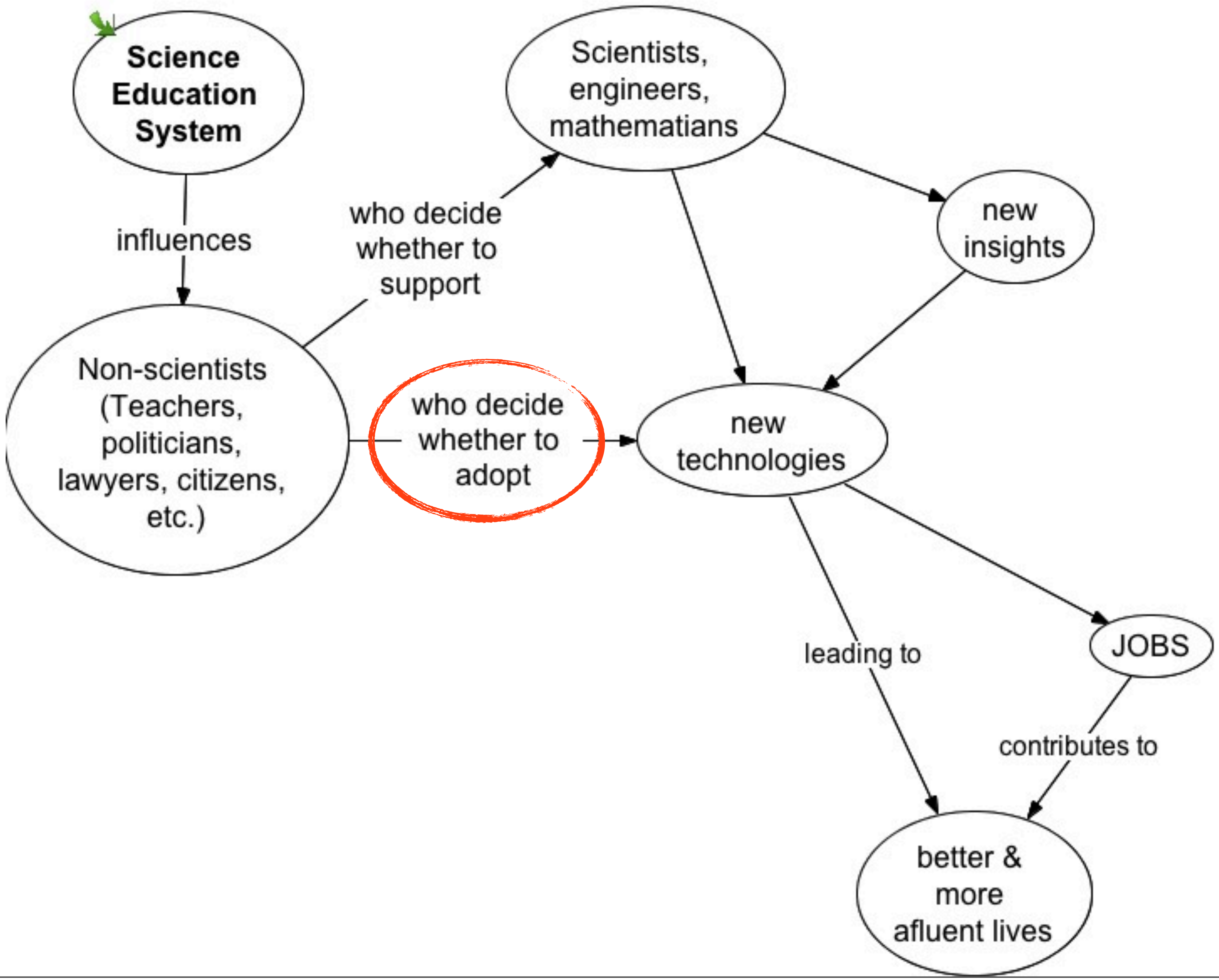
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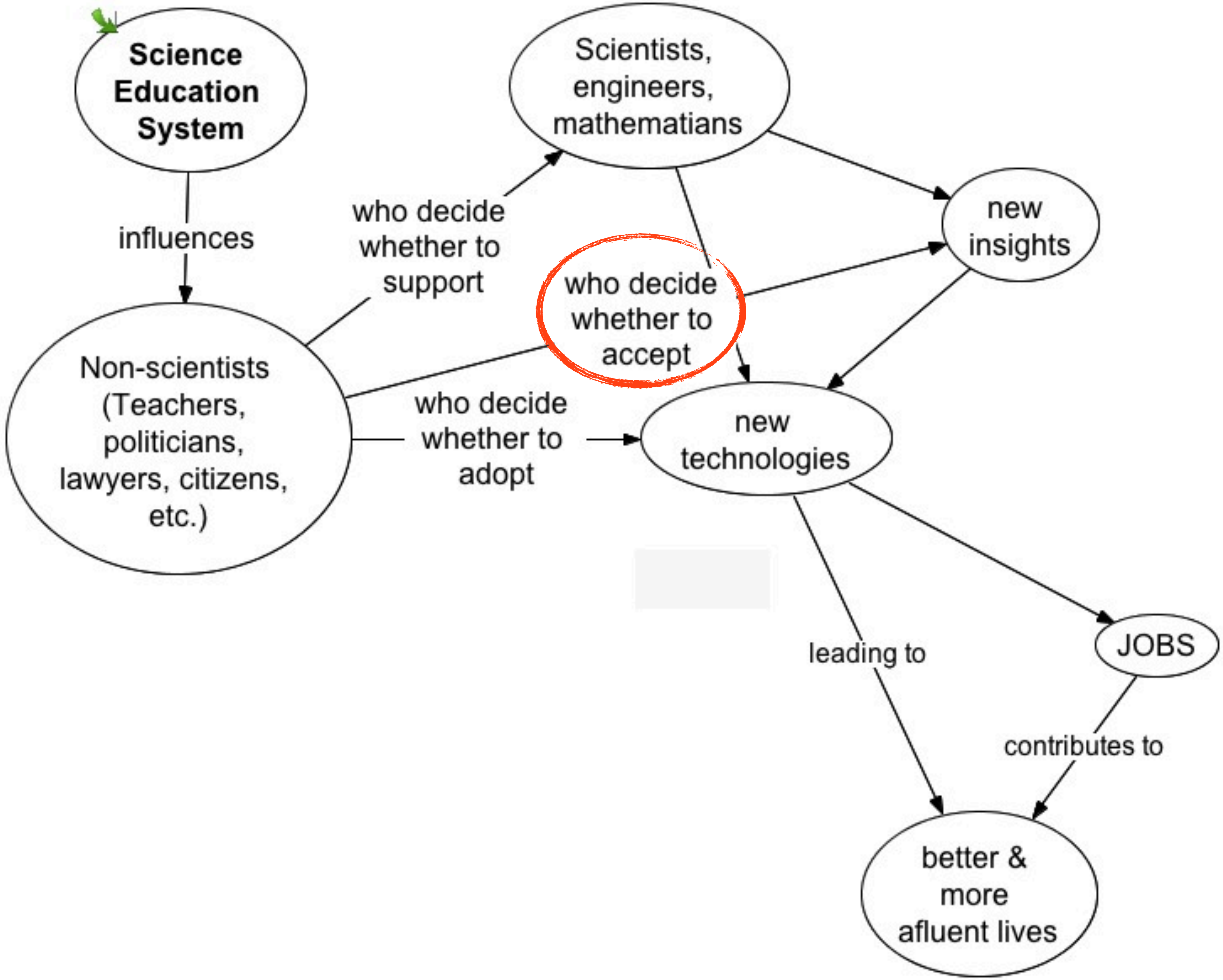
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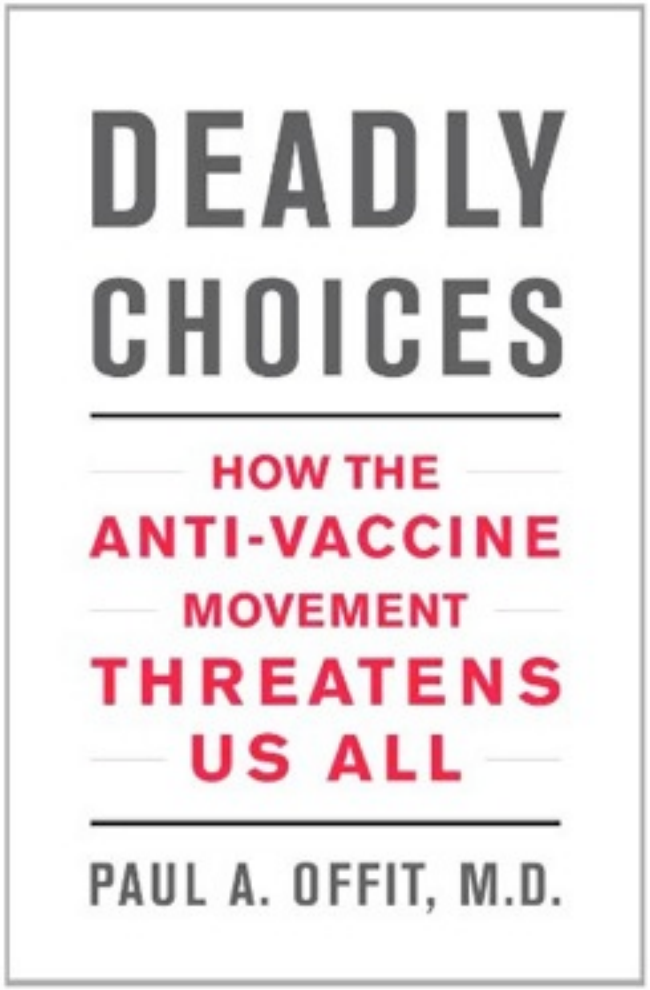
Newsweek
CRAZY TALK
OPRAH, WACKY CURES & YOU

# which is not without consequences



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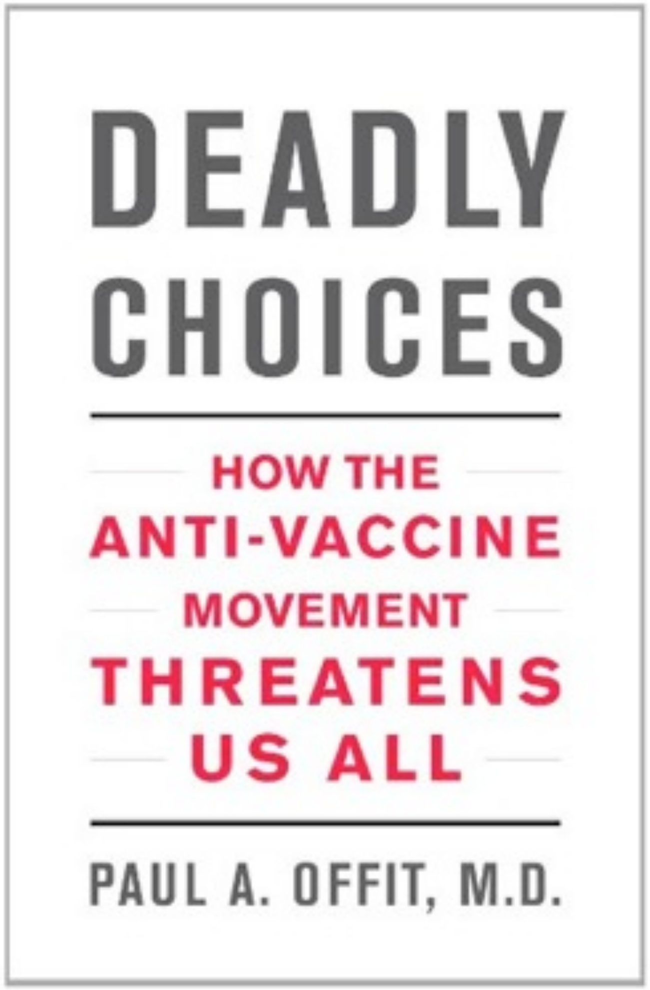
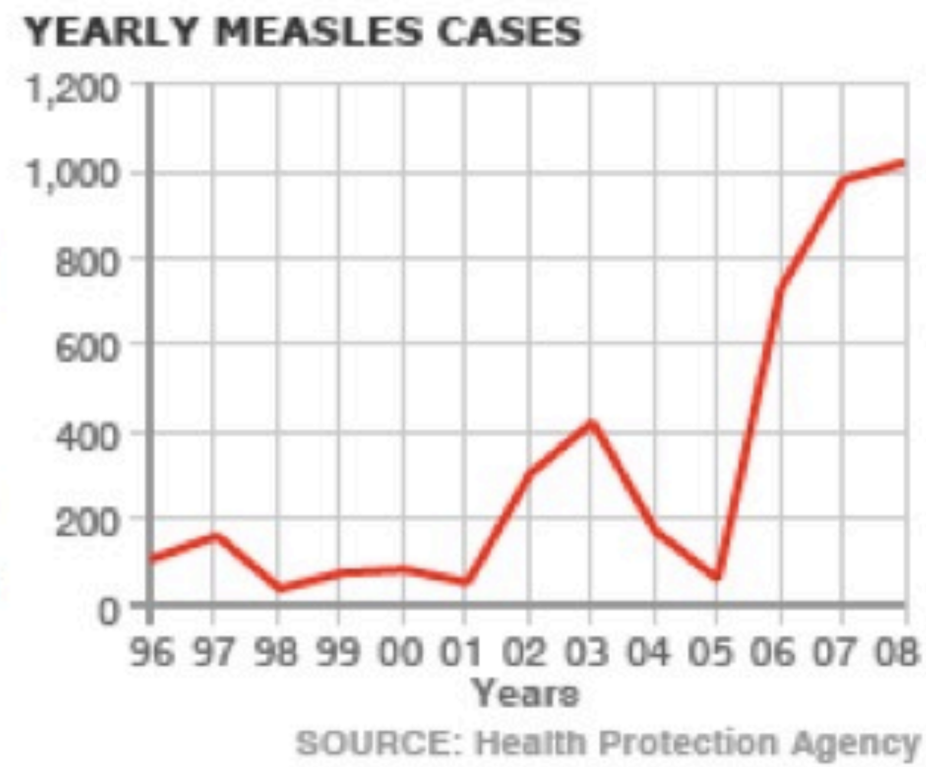



NOVEMBER 28, 2008

## 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:




> As many as one out of 20 children with measles gets pneumonia, and about one child in every 1,000 who get measles will develop encephalitis. (This is an inflammation of the brain that can lead to convulsions, and can leave your child deaf or mentally retarded.) For every 1,000 children who get measles, one or two will die from it.

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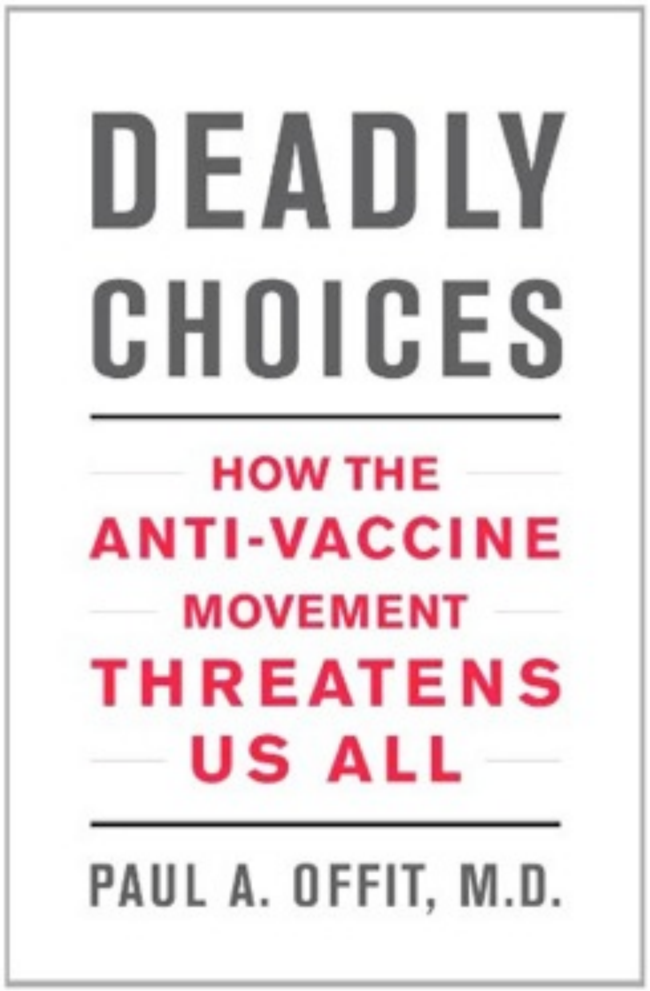


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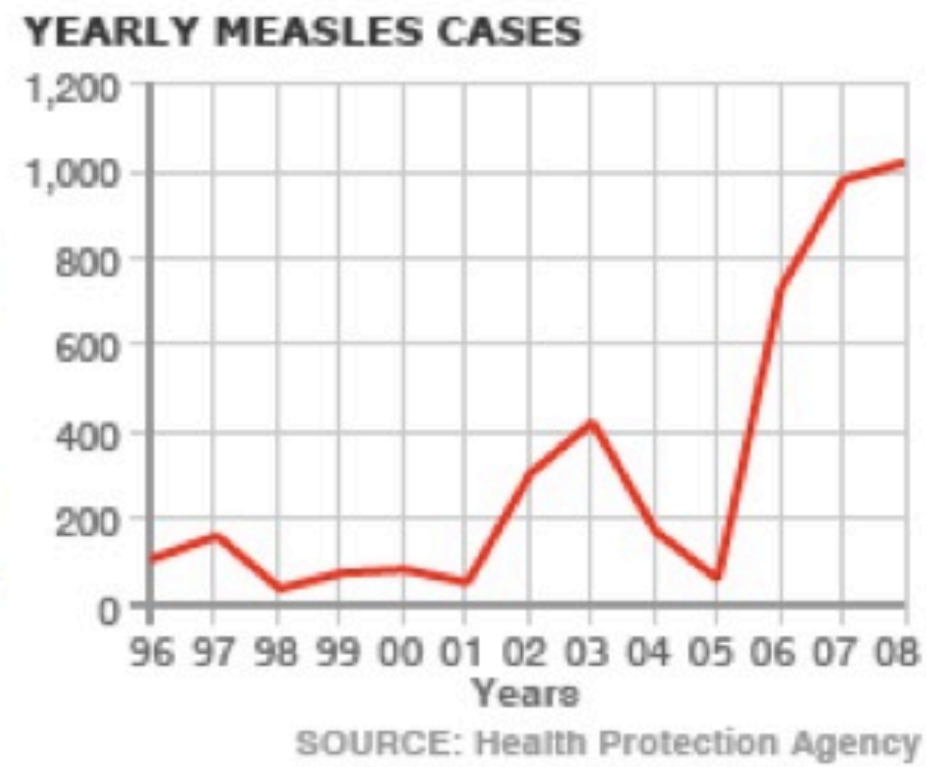


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# Louisiana's bold bid to privatize schools

Recommend 7,300 people recommend this. Be the first of your friends.

By Stephanie Simon
**June 1** | Fri Jun 1, 2012 6:04pm EDT

Tweet 464

The Upperroom Bible Church Academy in New Orleans, a bunker-like building with no windows or playground, also has plenty of slots open. It seeks to bring in 214 voucher students, worth up to $1.8 million in state funding.

At Eternity Christian Academy in Westlake, pastor-turned-principal Marie Carrier hopes to secure extra space to enroll 135 voucher students, though she now has room for just a few dozen. Her first- through eighth-grade students sit in cubicles for much of the day and move at their own pace through Christian workbooks, such as a beginning science text that explains "what God made" on each of the six days of creation. They are not exposed to the theory of evolution.

"We try to stay away from all those things that might confuse our children," Carrier said.

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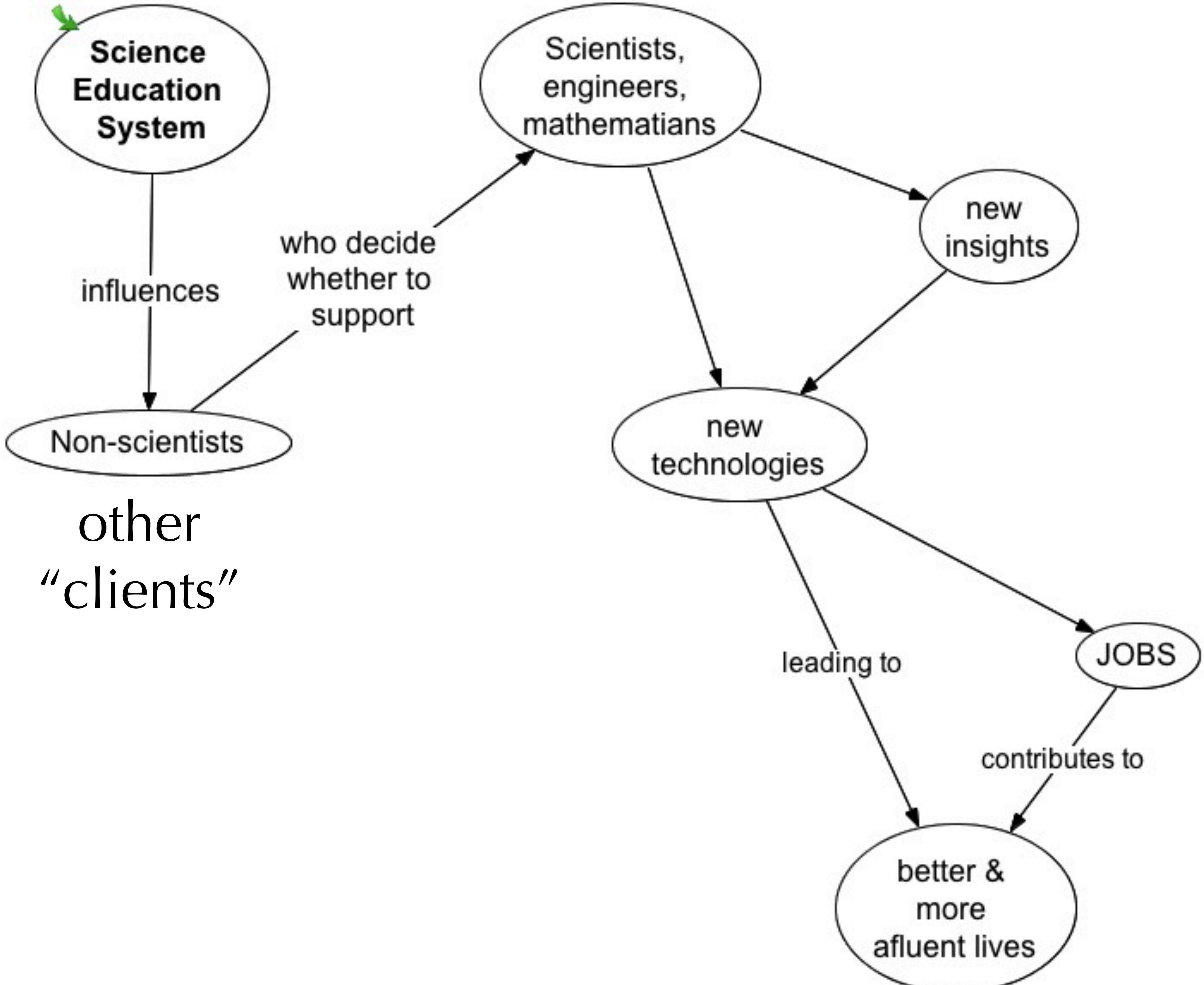
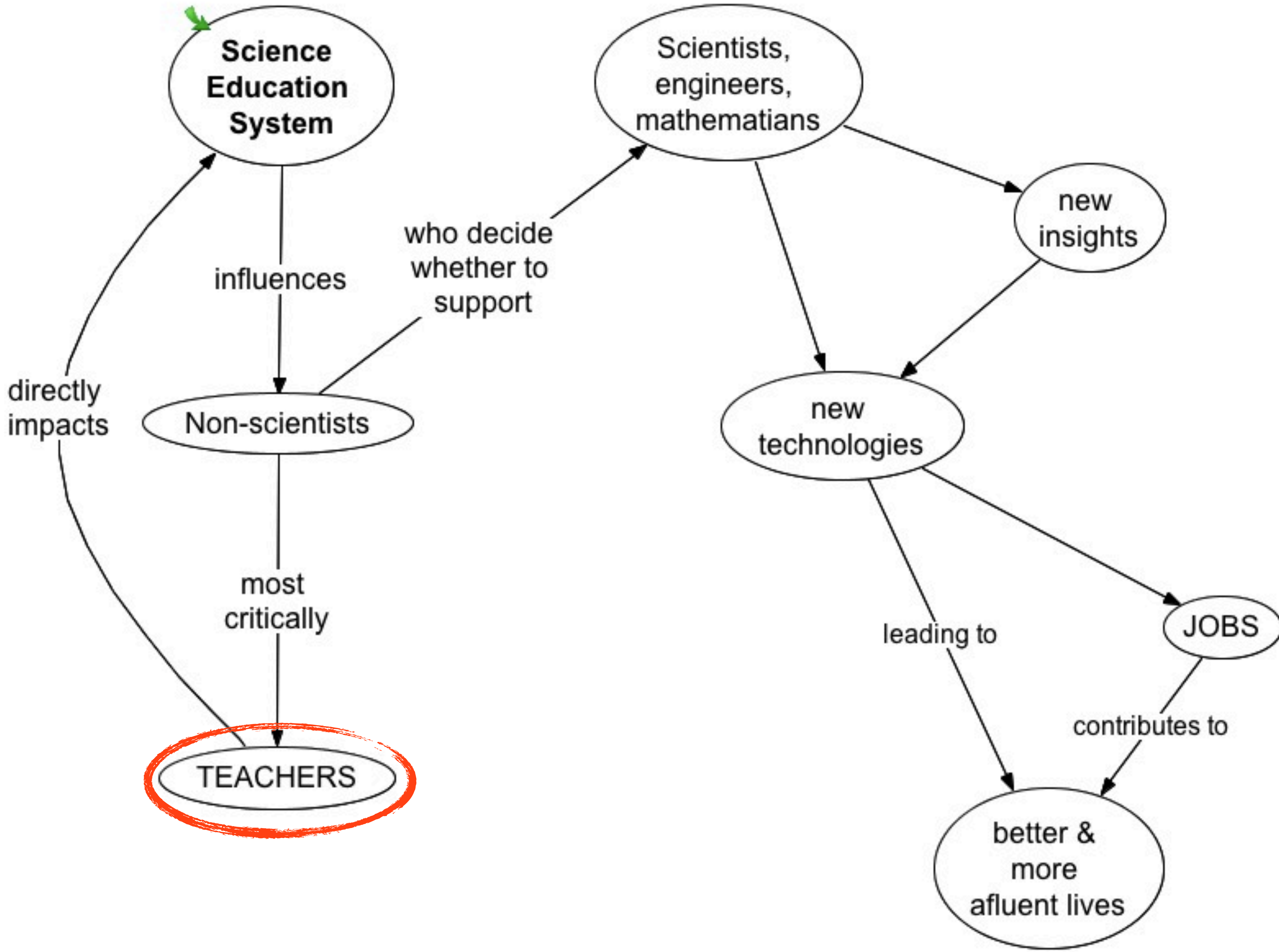



other "clients"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**Model I**: **Success** is in generating **scientists**
- equivalent of producing best selling authors, accomplished musicians, successful athletes and entrepreneurs)

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**Q: Does this come with unintended consequences for non-scientists?**

**Model II**: **Success** is teaching people to understand (teach) science: how to read, appreciate music, understand the “game”.

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**Q:** Should teachers be our "target" audience. Do they represent our most important student population?

**Q:** Would this improve learning outcomes for all students?

# either way, remember that scientific thinking is unnatural (hard)


Thinking fast and slow.
Daniel Kahneman (2011)

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**Now for the Hard Part: The Path to Coherent Curricular Design***

Received for publication, April 12, 2012, and in revised form, April 17, 2012

**Michael W. Klymkowsky‡ and Melanie M. Cooper§**

*From the ‡Department of MCD Biology/CU Teach, University of Colorado, Boulder, Colorado 80309-0347 and §Department of Chemistry, Clemson University, Clemson, South Carolina*

feature http://www.asbmb.org/asbmbtoday/asbmbtoday_article_print.aspx?id=13071

# Teaching disconcerting scientific ideas

BY MIKE KLYMKOWSKY

*Explaining the scientific process will help the public understand why scientists trust their own conclusions.*

## Strange scientific ideas

- Matter is composed of atoms, which are mostly empty space.
- The universe emerged out of nothing (about 13,700,000,000 years ago).
- There are billions of galaxies, each containing billions of stars.
- Time and space are not distinct.
- All organisms are built from similar building blocks called cells.
- All cells are derived from pre-existing cells in a continual lineage that extends back about 3,500,000,000 years.
- The heavier atoms in our bodies were formed within stars or exploding stars.
- Matter and energy are different versions of the same thing.
- The universe is running down yet expanding at a faster and faster rate.
- Random noise can produce complex structures.
- At the molecular level, everything is reversible.
- A collection of cells can, by itself, produce a self-conscious entity that thinks it is more than a collection of cells.

*feature* http://www.asbmb.org/asbmbtoday/asbmbtoday_article_print.aspx?id=13071

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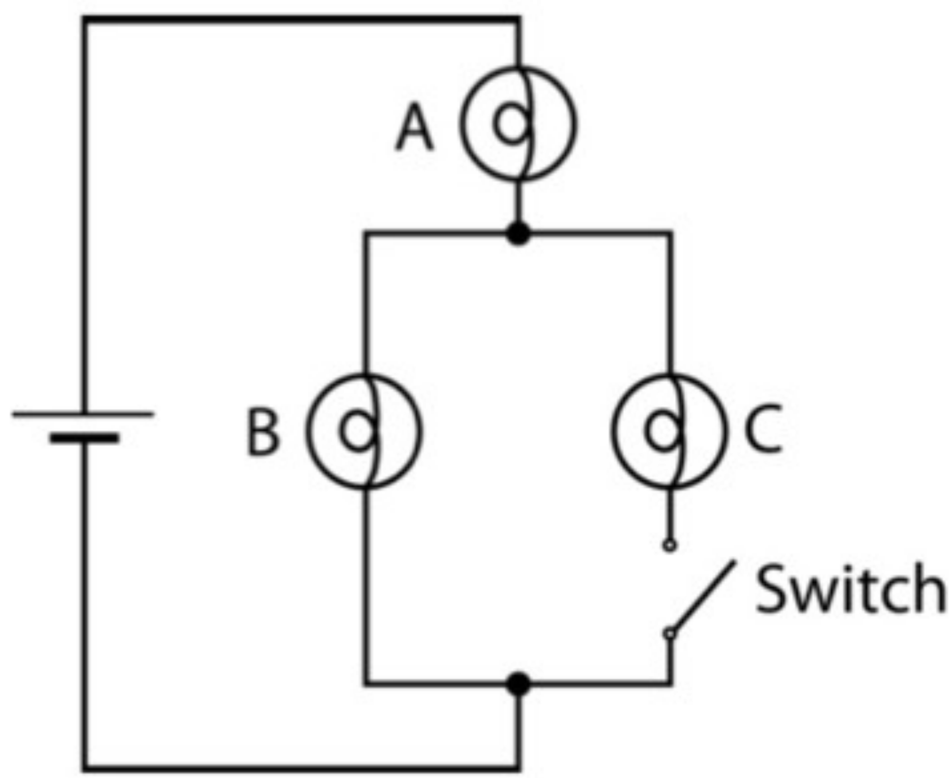
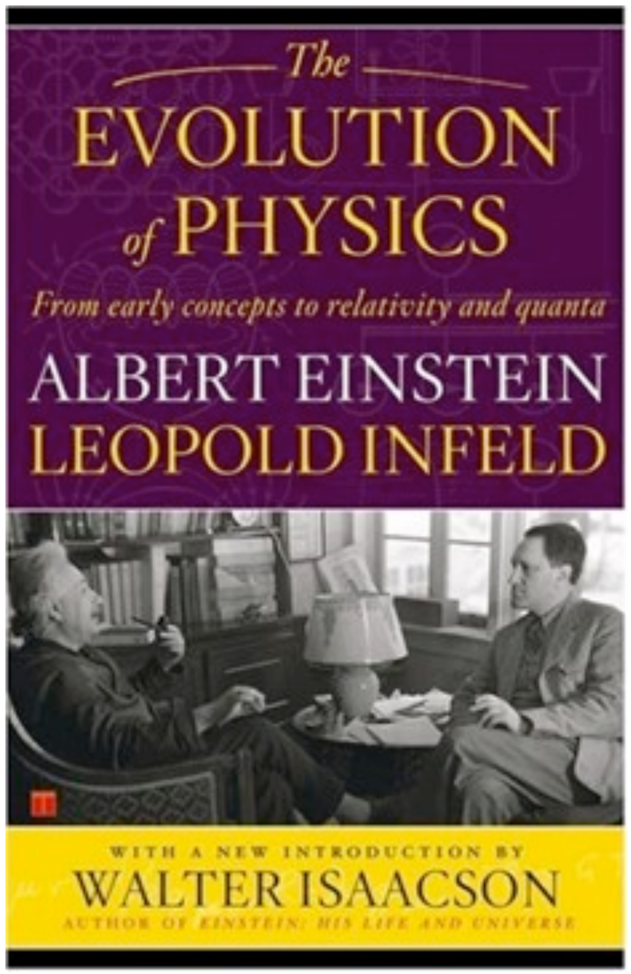


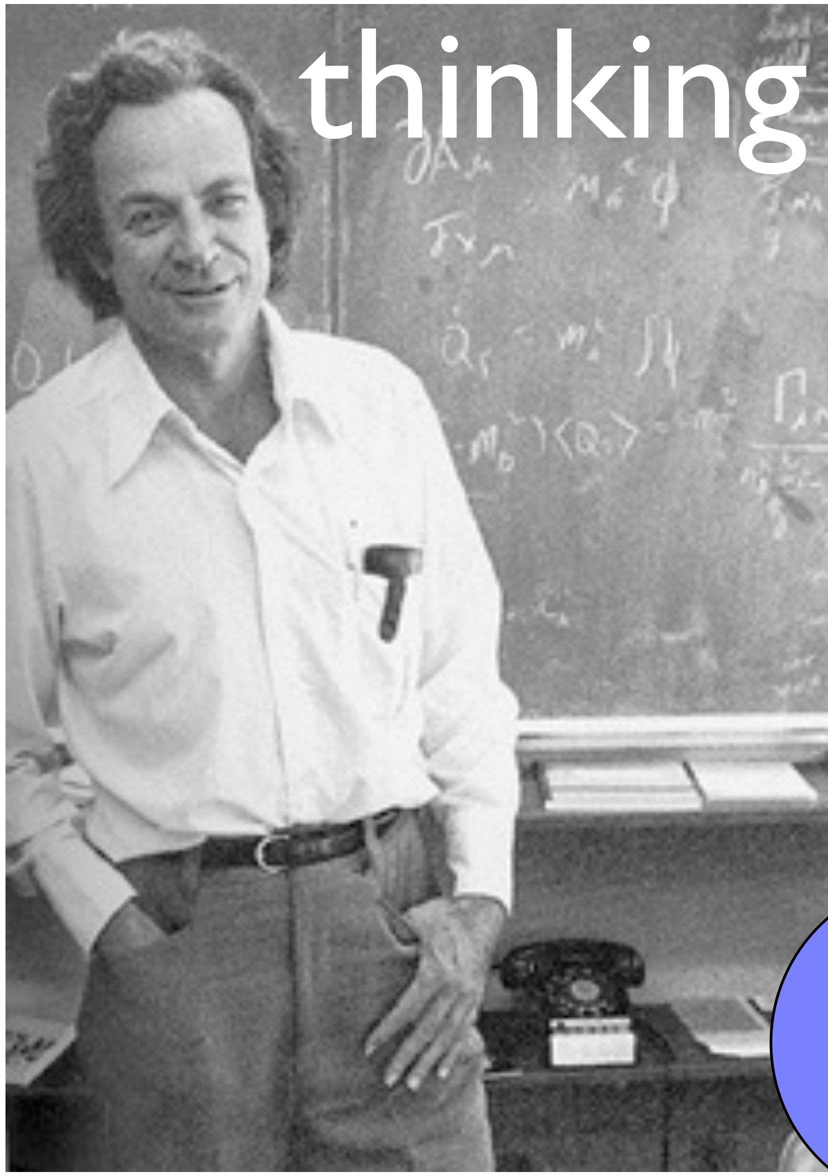


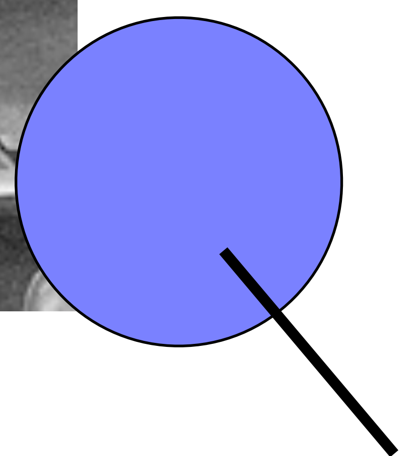

# "...new physical concepts are born in the painful struggle with old ideas."

- Einstein & Infeld, 1967. The Evolution of Physics.

# understanding builds on foundations:

## thinking about magnets





what the student knows
(or thinks they know)

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

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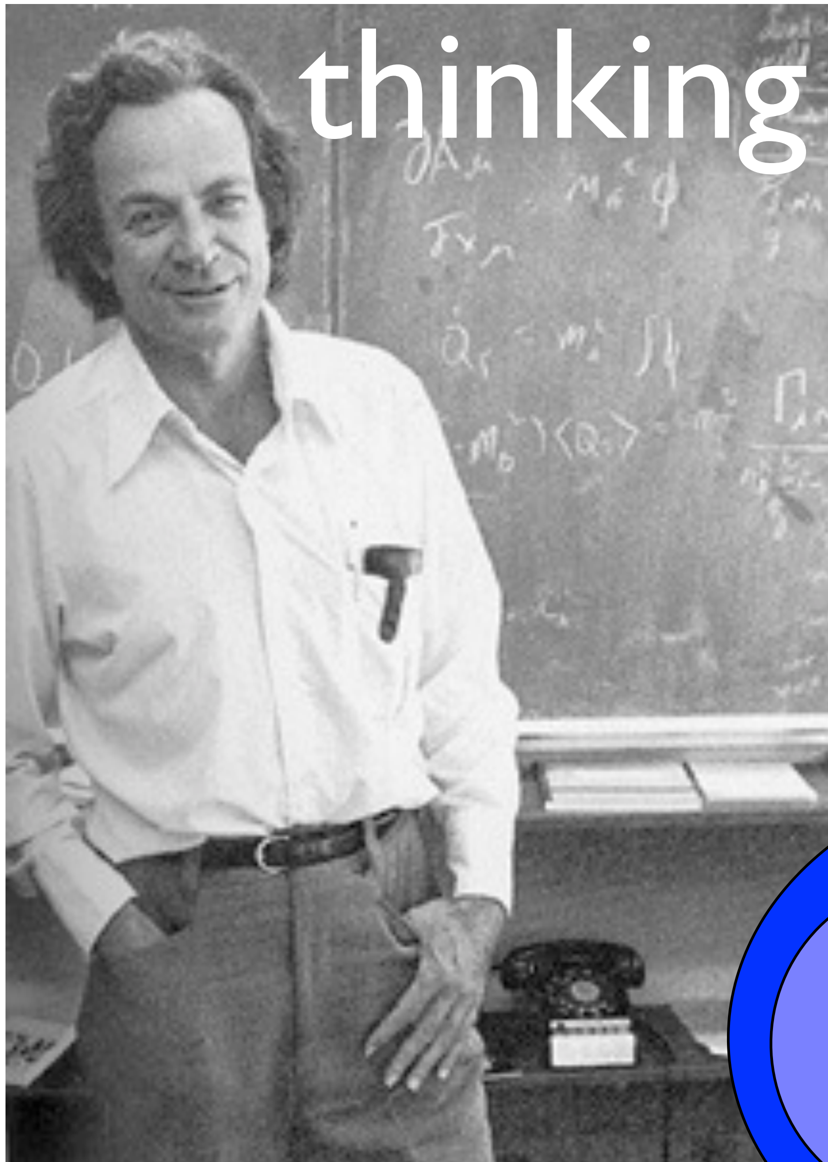

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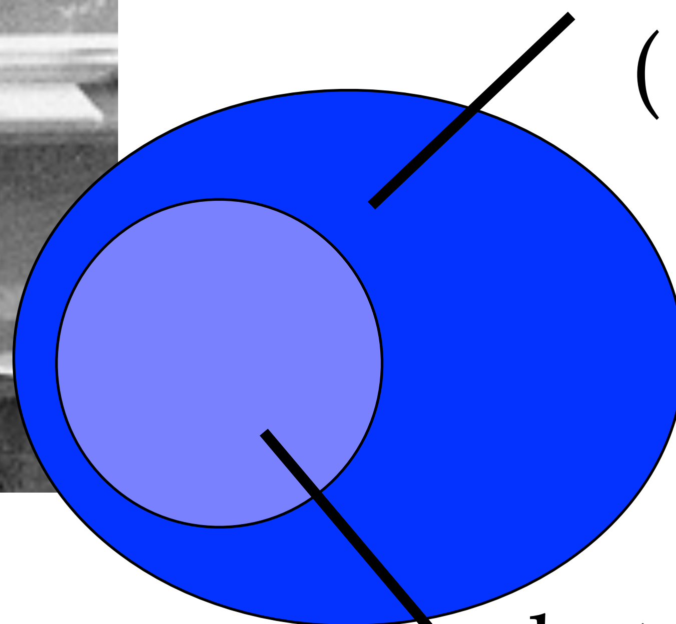

what the student could learn
( with help, i.e. teaching)

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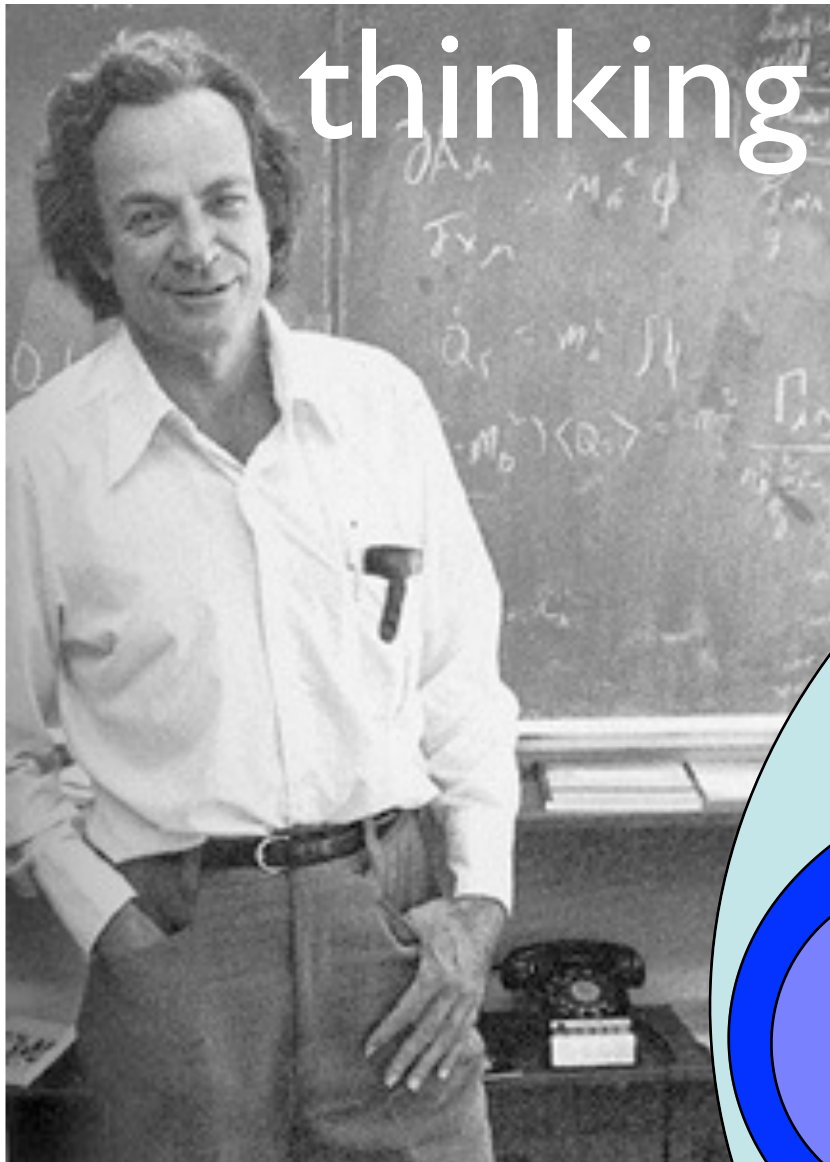

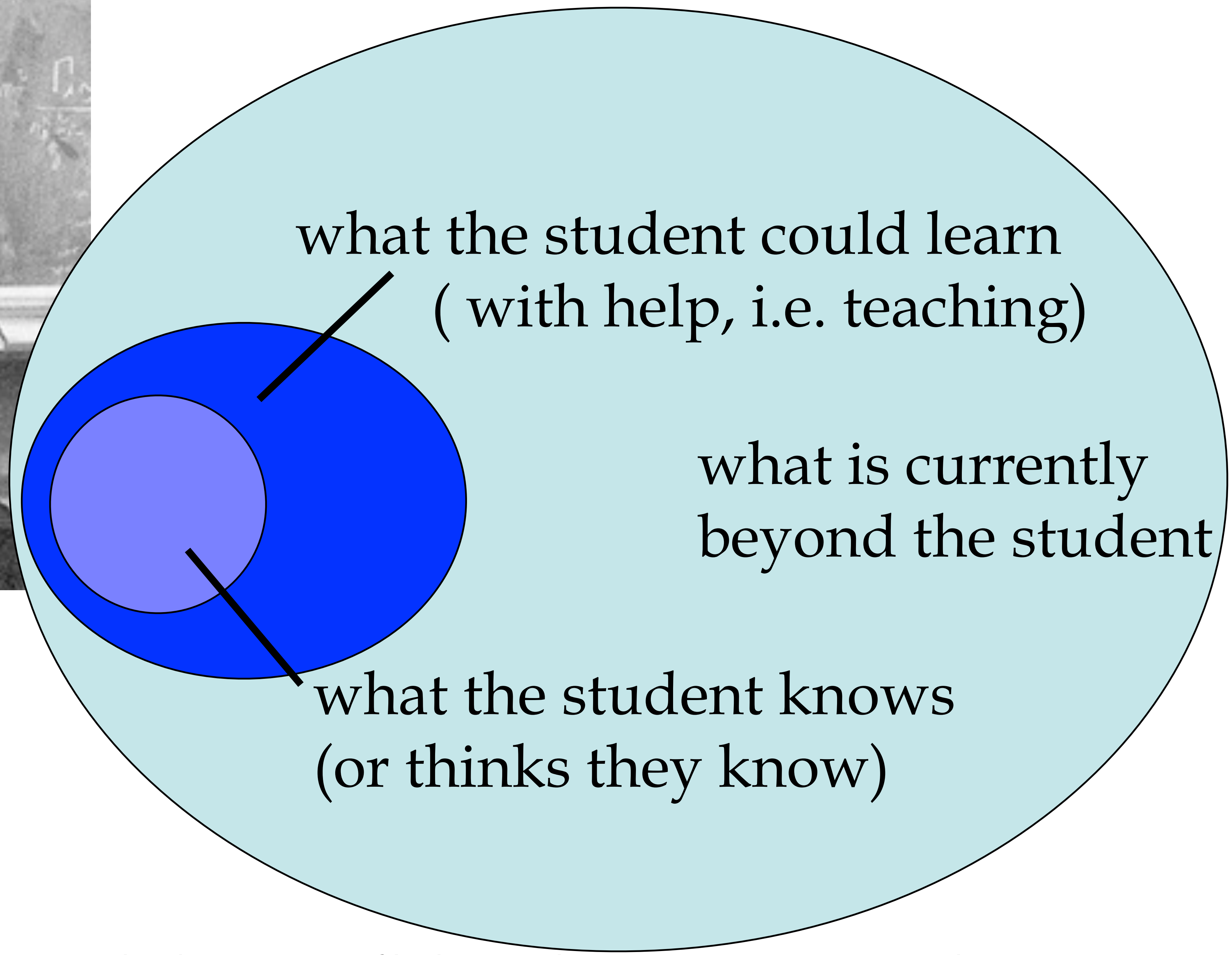


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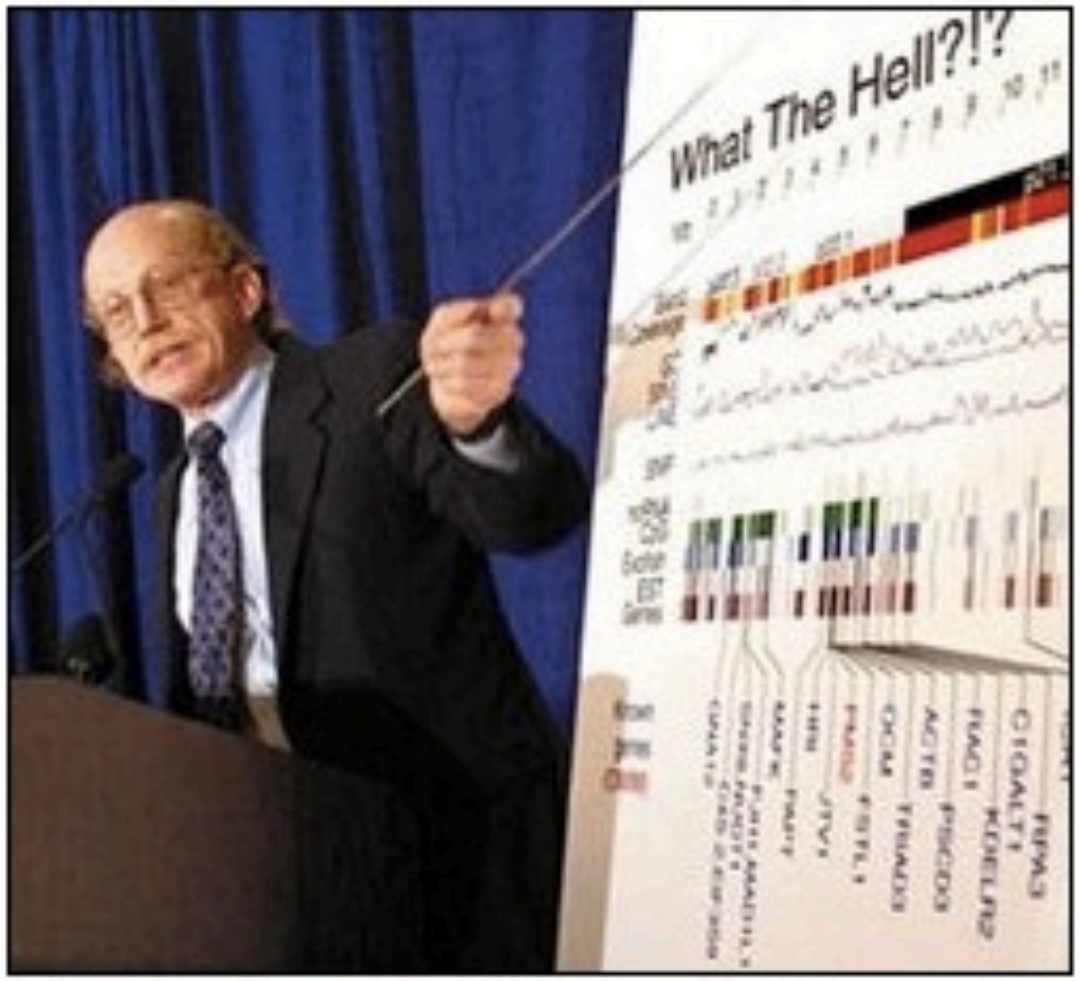
# National Science Foundation: Science Hard

JUNE 5, 2002 | ISSUE 45•01 ISSUE 38•21

INDIANAPOLIS—The National Science Foundation's annual symposium concluded Monday, with the 1,500 scientists in attendance reaching the consensus that science is hard.

Enlarge Image



Farian explains the NSF findings.

"For centuries, we have embraced the pursuit of scientific knowledge as one of the noblest and worthiest of human endeavors, one leading to the enrichment of mankind both today and for future generations," said keynote speaker and NSF chairman Louis Farian. "However, a breakthrough discovery is challenging our long-held perceptions about our discipline—the discovery that science is really, really hard."

"My area of expertise is the totally impossible science of particle physics," Farian continued, "but, indeed, this newly discovered 'Law of Difficulty' holds true for all branches of science, from astronomy to molecular biology and everything in between."

**RELATED ARTICLES**

Report: Majority Of ADD Cases Go Undiagnosed Until Child's First Public Failure
02.27.11

Deaths Of 550,000 Confirm Which Mushrooms Are Okay To Eat
12.14.09

# What are we expecting to achieve, exactly?

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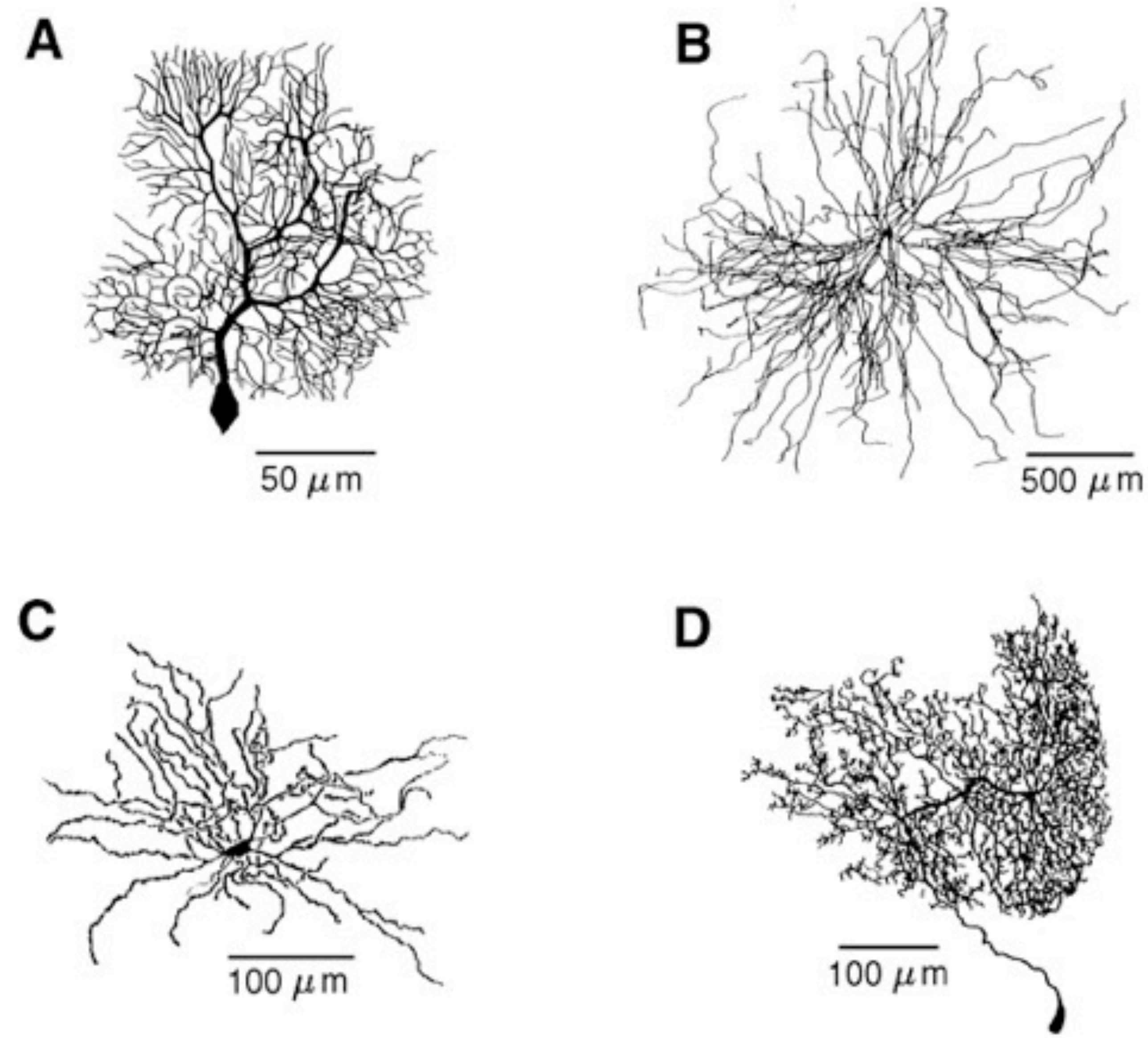
What do these expectations imply about what students need to know?

**Are they attainable?**

or do they require curriculum redesign?

# NGSS draft performace expectation:
Model the development of long term memory



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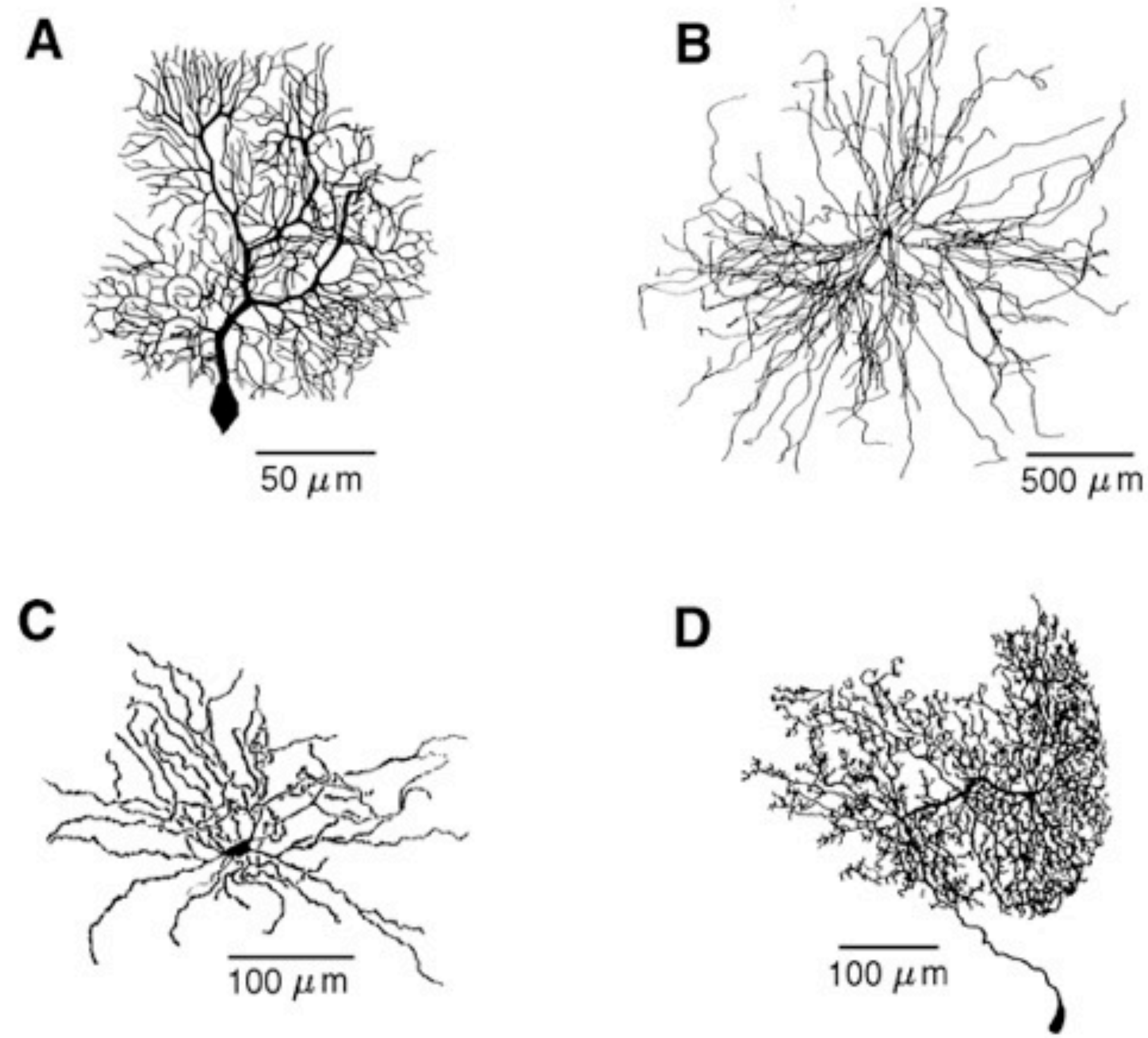
**Superficial** - cells change



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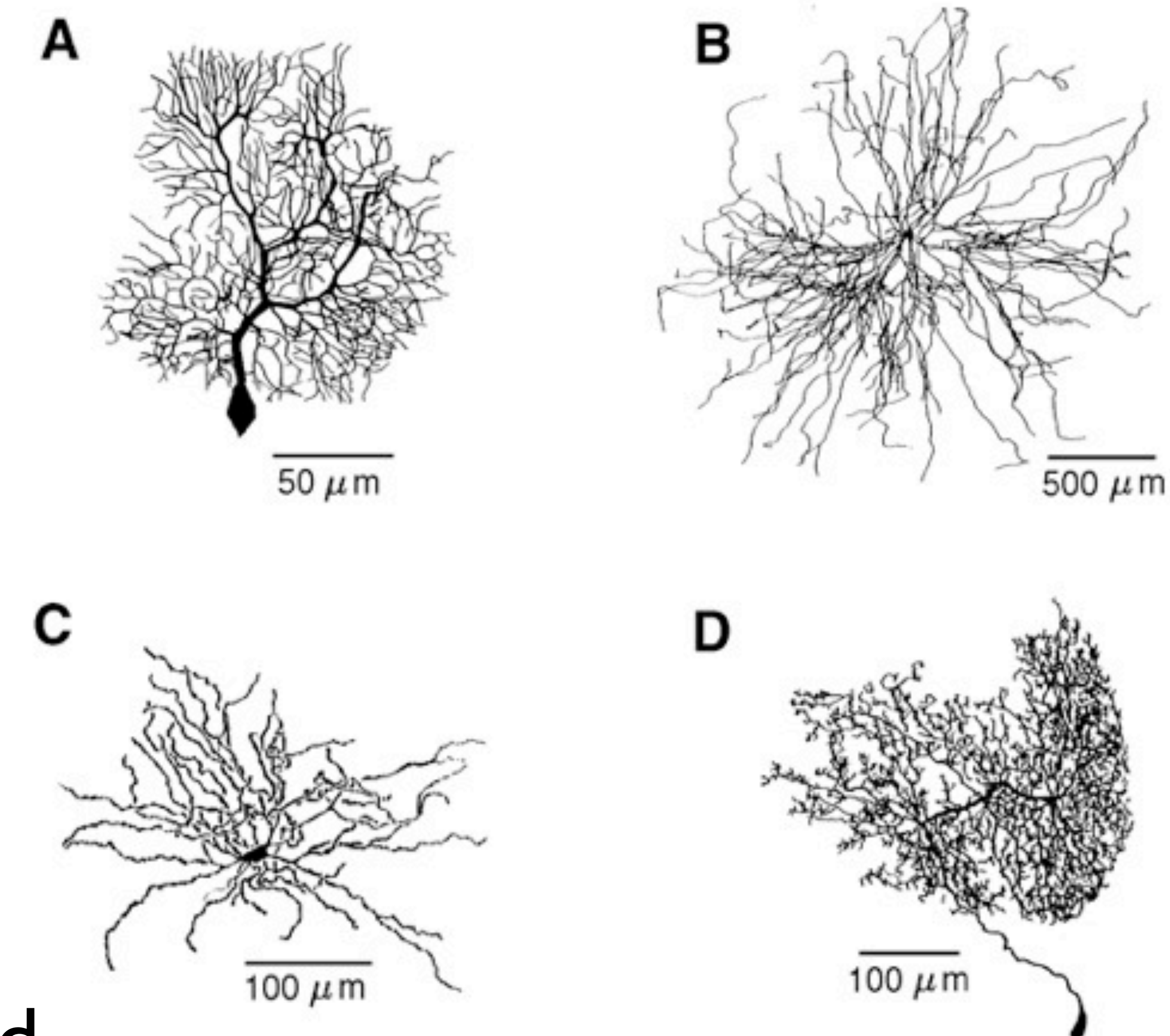


**Neurobiological**:
sensory inputs combine with pre-existing cellular and network structure (and activity) through coordinated changes cellular morphology, synaptic position, structure, and efficiency, the integration of excitatory and inhibitory activity, firing rates, and timing $\Rrightarrow$ changes in the activity of the neural networks that is linked (somehow) to detailed memory.

Cell Biology Reformation – UC Boulder

http://virtuallaboratory.colorado.edu/Cell+Molecular/index.html

News Lab PubMed CLUE arts Dish BioFundamentals

*omnis cellula e cellula*

*knowledge statements & performance expectations*

*core curriculum design / home*

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Evolutionary basics
Biomolecules
Molecular machines

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Cell theory
Cells as systems
Membrane structure
Membrane function
Cytoplasmic systems
& intracellular organelles
Cell polarity: junctions
& extracellular matrix
Genomic organization
Genes & their expression
Genetics

Signaling interactions

Cell & organismic replication
Cell death and disease

The social life of cells

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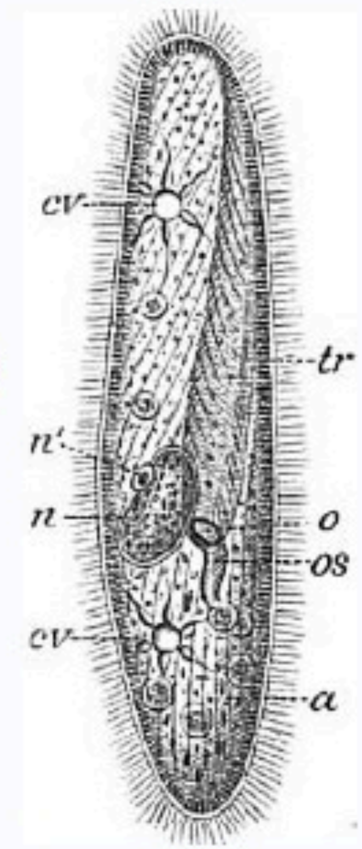
Highlighter

## *Rethinking cell & molecular biology curricula*




The design of this project reflects many fruitful interactions, including discussions with faculty from the School of Education (CU Teach) and the general science education community.

It builds on lessons learned in the development and evolution of Biofundamentals, an "alternative" introductory course in modern biology (read a student's view of the course here). Biofundamentals itself was inspired by observations made during the National Science Foundation (NSF)-funded Biology Concept Inventory (BCI) project, a collaboration with Kathy Garvin-Doxas.

Equally critical have been the lessons learned in the course of developing CLUE: Chemistry, Life, the Universe & Everything, an NSF-funded general chemistry curriculum. In particular, CLUE, Biofundamentals, and OrganicPad inspired the development of BeSocratic, a novel graphics-based formative assessment system, made possible by the briliant programming efforts of Sam Bryfczynski (now joined by Josiah Hester) and supported in part by funds from the NSF.

Biofundamentals, CLUE and the Cell & Molecular Biology project embrace technologies (beSocratic and Highligher) that make the text socially interactive and evolvable and that provide students with challenging activities to hone their understanding of often difficult ideas.

Finally, we acknowledge the HHMI CourseSource project team, which has emphasized the importance of conceptually coherent and pedagogially effective curricula in modern biology

Comments on the ideas presented here are very welcome
- Mike Klymkowsky & Melanie Cooper.

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# Performance expectations & knowledge statements

http://virtuallaboratory.colorado.edu/Cell+Molecular/

**a cell biological performance expectation:**

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**a cell biological performance expectation:**

Students should be able to:
i) develop a model for how various proteins come to be localized in various parts of the cell; and ii) use that model to predict the effects of mutation on protein localization.

**Should include:**

- polypeptide synthesis occurs in the cytoplasm
  - it is vectorial (from N- to C-terminus).
- often continues until polypeptide's synthesis is complete
  - can be paused allowing movement rto the endoplasmic reticulum (ER)
    - based on signal sequence/SRP and its interaction with ER-associated receptor/translocation complex
    - allows translation to resume, polypeptide enters ER membrane
- cytoplasmic polypeptides that are components of multisubunit proteins interact with molecular chaperones to assemble protein.
- presumes the pre-existence of cellular machinery (The Cell Theory).
- some cytoplasmic proteins remain cytoplasmic because they are too large to move (via diffusion) through the nuclear pore complex (NPC)
- some, small enough to pass through the NPC, accumulate within the nucleus because they bind to intranuclear components, such as chromatin.

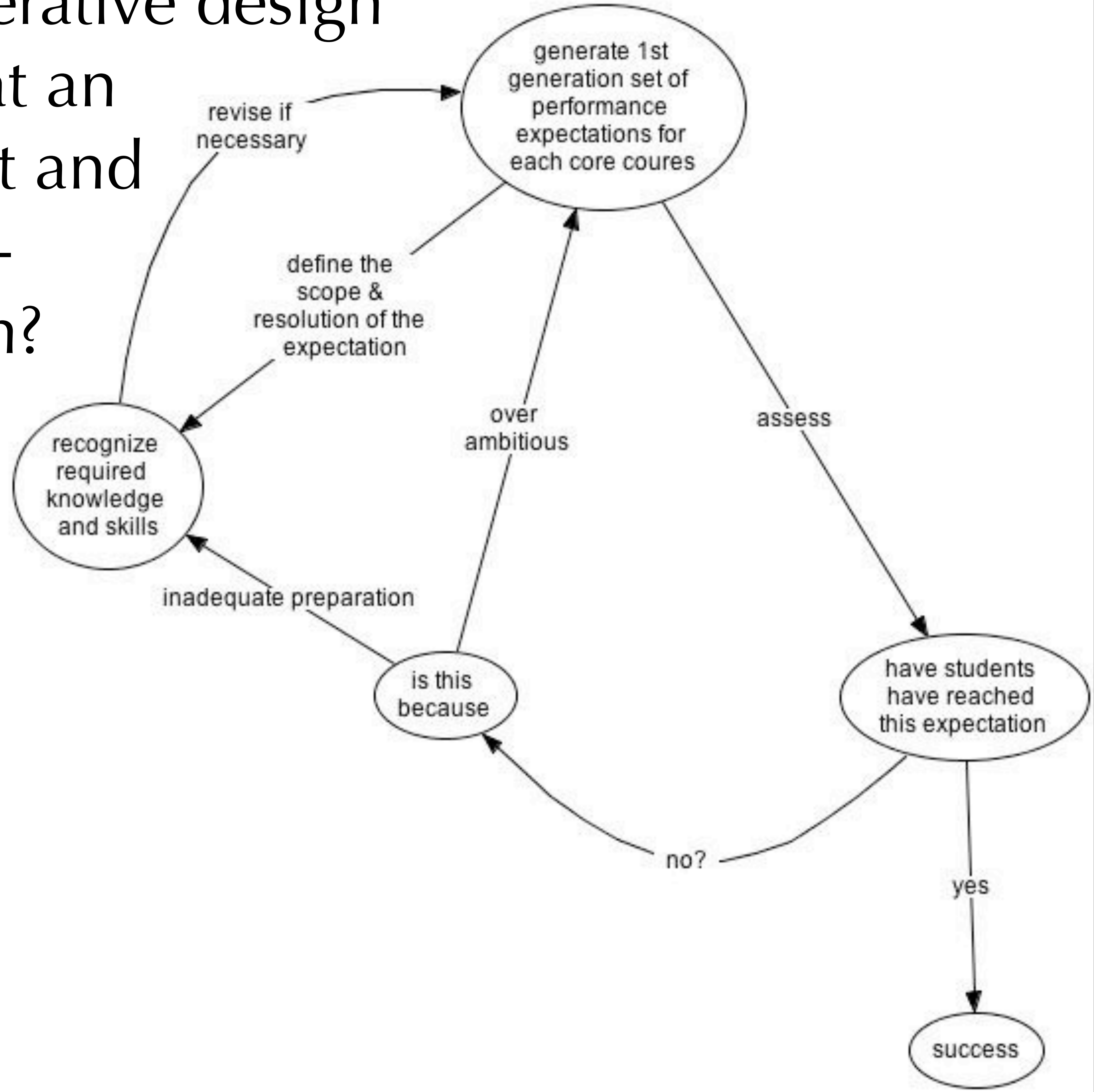
**a cell biological performance expectation:**

students should be able to develop a model for how various proteins come to be located in various parts of the cell, and based on that model predict the effects of various types of mutations on protein localization

**Should include (continue):**

- Larger, nuclearly localized molecules rely on various active, that is, generally ATP-hydrolysis coupled, reactions, involving the NPC transport machinery and nuclear localization sequences (NLS).
- nuclear exclusion sequence (NES) lead to active transport out of the nucleus
- Both NLSs and NESs activity can be regulated
- macromolecular assembly can involve transport of components from the cytoplasm to the nucleus and then back to the cytoplasm.
- cytoplasmic proteins can be transported into intracellular organelles.
- ER protein can be localized to various various organelles or delivered to the plasma membrane
- proteins secreted from one cell can be taken up by other cells
- There are various “quality control” mechanisms that facilitate the return of mislocalized proteins to their correct locations or refolding, and if unsuccessful, the degradation of misfolded or mislocalized proteins

# Can we use a reiterative design process to arrive at an effective, coherent and realistic “learning-based” curriculum?



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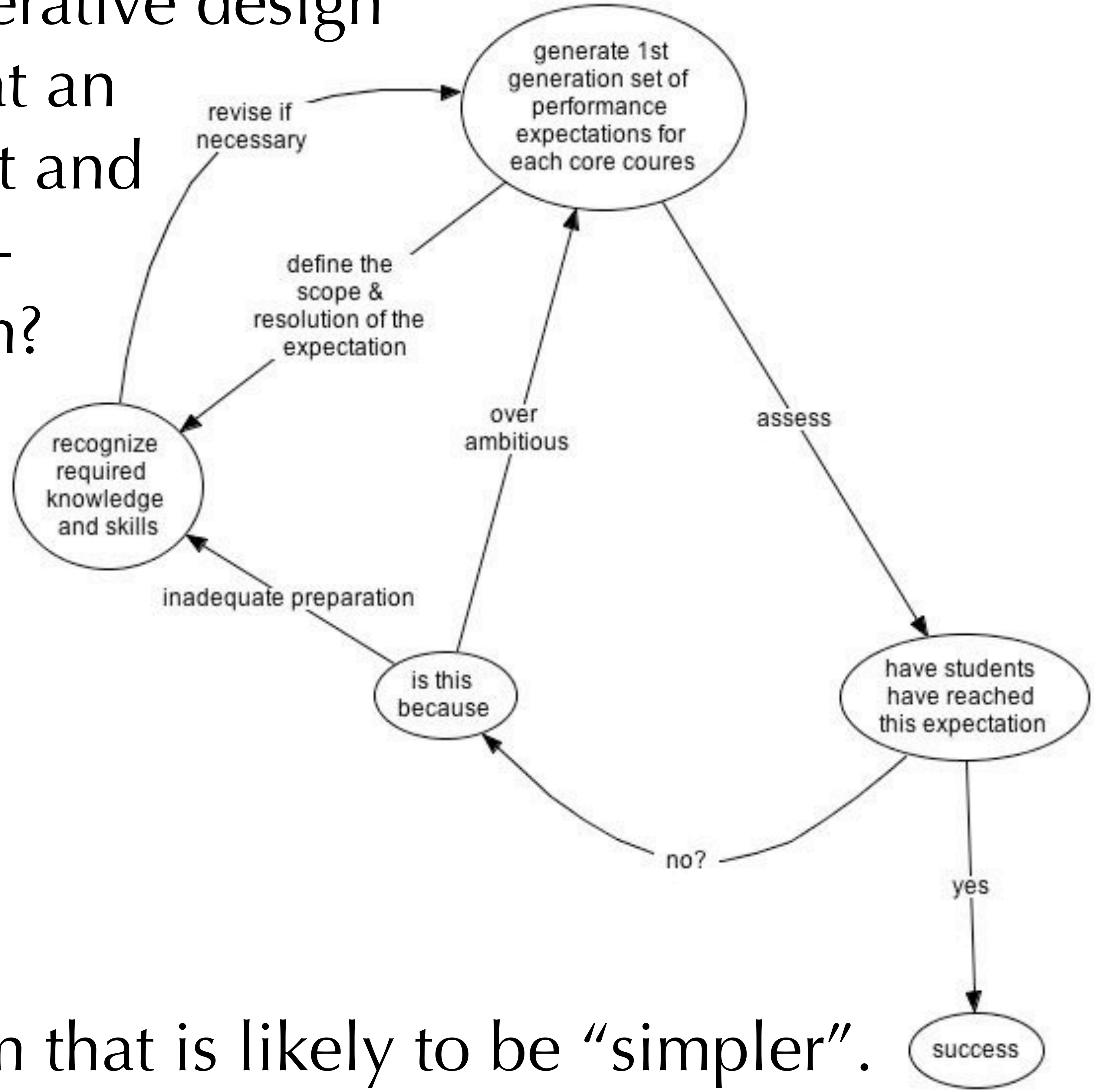


A curriculum that is likely to be “simpler”.

# to be a little provocative....

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How can we cooperate effectively?
Can we all get along?

We are involved in three efforts at building coherent courses.

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**BIOFUNDAMENTALS**

(to replace intro. molecular biology)

We are involved in three efforts at building coherent courses.

**BIOFUNDAMENTALS**

(to replace intro. molecular biology)

**CLUE-CHEMISTRY (w. Melanie Cooper)**

(to replace intro. chemistry)

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(to replace intro. molecular biology)

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(to replace intro. chemistry)

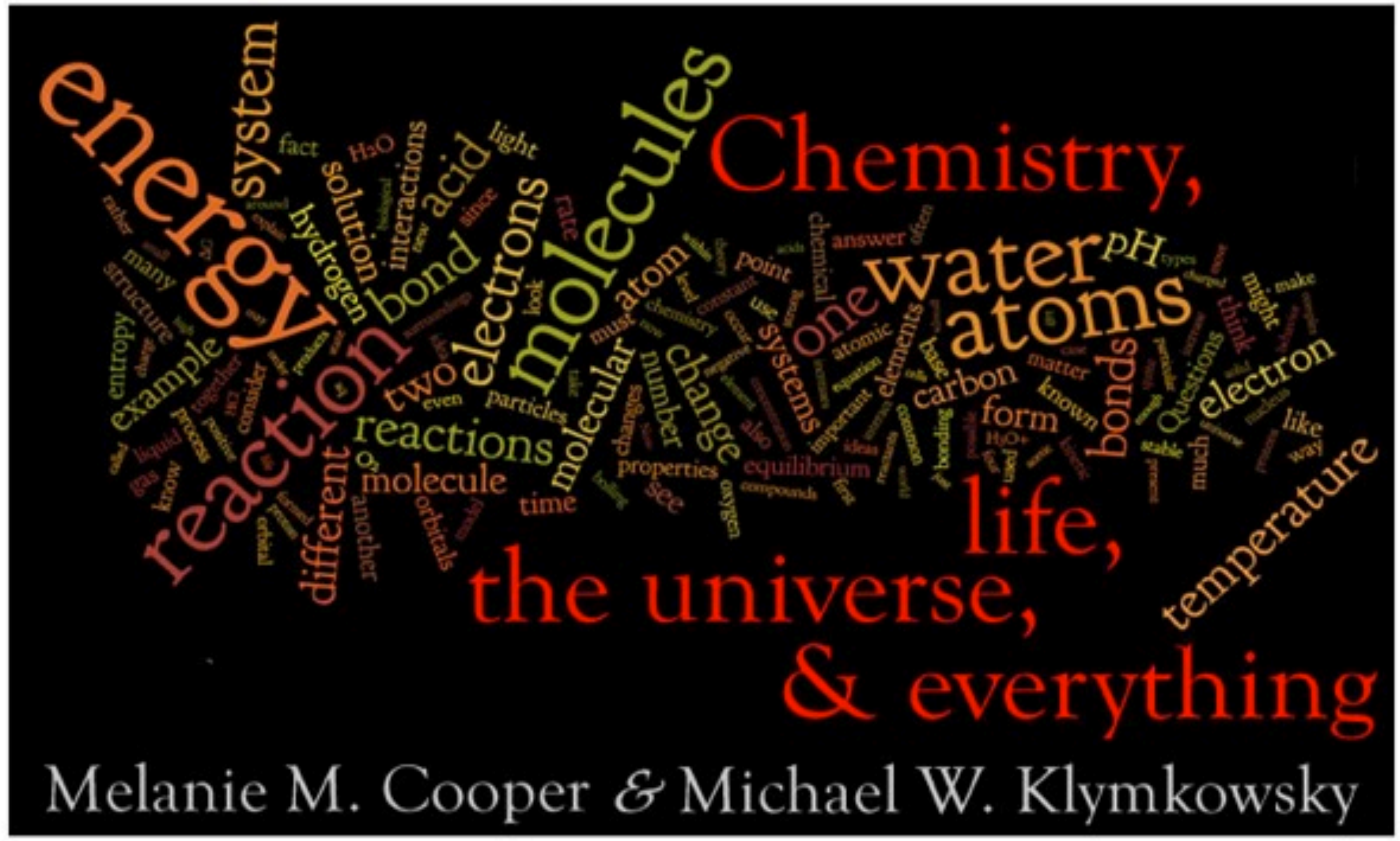
**CALCULUS, STOCHASTICS & MODELING (CSM)**
**(w. Eric Stade)**(to replace calculus 1)

CLUE: Chemistry, Life,
the Universe & Everythinng



Biofundamentals
introductory biology






**Chemistry** is a fascinating science, but one with a public relations problem, due in part to the way traditional general chemistry courses are taught. Yet understanding chemistry is foundational for a wide range of scientific disciplines.

There is therefore a compelling reason to provide a coherent and rigorous context (and text) that effectively engages students (even those not destined to become chemists); an approach that helps them master a difficult, abstract and often counter-intuitive subject prone towide-ranging pre- and misconceptions.

We have approached these issues head-on through a substantial research effort to understand student thinking and student's responses to the materials we have generated.

The CLUE curriculum has now been taught a number of times, at a number of institutions, and we have found robust learning outcomes. If you are interested in beta-testing these materials in your own class room, please let us know.

funded in part by the National Science Foundation Highlighter → preface & background

**Melanie Cooper** will go into more detail tomorrow
(so rebook your flight!!!!)

**Biofundamentals™**

syllabus | home | blog
course information - question

Being Biofundamental
Science & its Methods
Life's Origins
Evolution's logic
  Speciation & Extinction
  Adaptation & Selection
  Predators, Prey & Mates
  Non-Adaptive Processes
  Homology & Analogy

Water & Life's Structure
Lipids & Membranes
  Getting through Membranes
  Carriers, Pore & Pumps
A (very) little thermodynamics
  Capturing Energy
  Storing Energy
  Eukaryotic Symbiosis

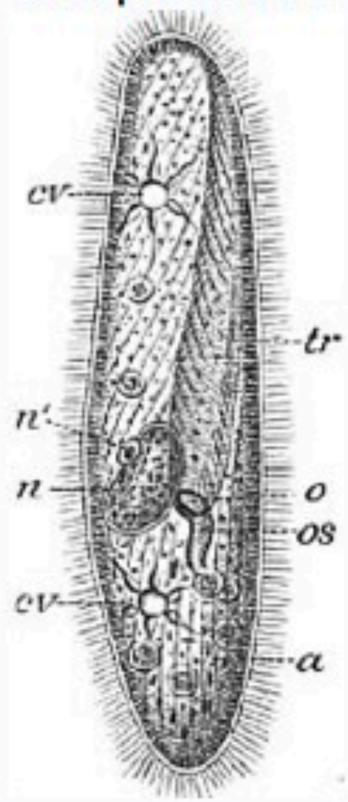
Chemical basis of heredity
  Nucleic Acid Structure
  DNA replication
  Mutations & Repair
Peptide Bonds & Polypeptides
  Making Polypeptides
  Assemblying Proteins
  Regulating Protein Activities

Regulating gene expression
Regulatory networks
Cell Divison
  Life cycles & Sex
  Stem Cells & Differentiation
Cellular communities
Eusocial and Antisocial behavior

**Biofundamentals™** (MCDB 1150) is an attempt to build a more conceptually coherent and rigorous introductory course in modern biology (testimonial)


We use an interactive teaching style and web tools to "get Socratic". You need to read and engage with the text and embedded assignments **before** class.

To insure that you do, highligher functions are incorporated throughout.




As you read you can leave comments and respond to the comments left by other students. Class time is spent considering the most difficult ideas.

Our goal is to help students master and apply difficult ideas, not sort them.

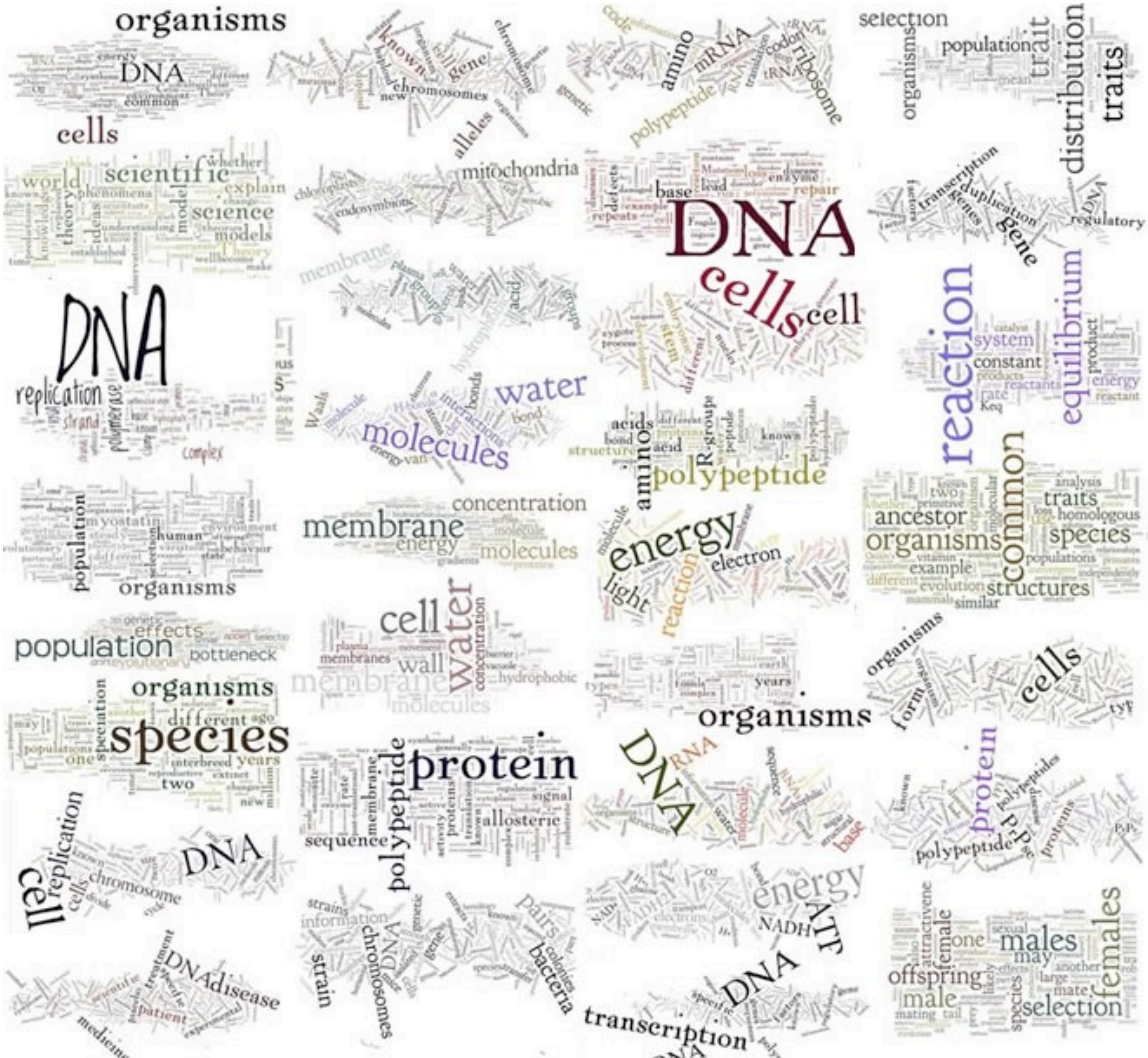
We use a novel testing strategy that includes "I know it now!©" tests designed to allow students to demonstrate their understanding of key ideas. **→IKiN LiNK←**

Biofundamentals™ is part of a larger course and curricular redesign effort described in more detail at the beSocratic.coloado.edu web site.

MERLOT Multimedia Educational Resource for Learning and Online Teaching    Highlighter    →



link to: *rethinking the cell & molecular biology curriculum*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DNA
cells
scientific
science
models
theory
DNA
replication
polymerase
complex
population
organisms
population
bottleneck
organisms
species
different
speciation
years
two
cell
replication
chromosome
DNA
DNAdisease
medicine
patient
treatment
known
gene
chromosomes
alleles
mitochondria
endosymbiotic
membrane
water
molecules
interactions
membrane
concentration
energy
molecules
cell
water
wall
membrane
molecules
concentration
hydrophobic
protein
polypeptide
membrane
sequence
allosteric
signal
strain
chromosomes
DNA
bacteria
pairs
amino
mRNA
ribosome
polypeptide
tRNA
codon
DNA
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energy
light
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years
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energy
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population
trait
distribution
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duplication
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equilibrium
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form
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females
males
male
offspring
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female
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# LISTEN TO STUDENTS (talking to students)

because the population has no "genetic memory" of its s...

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 appea... (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 depe...

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

---

H 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

---

**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?

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

**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 ...

# USE Multiple FORMS OF "CONCEPTUAL ASSESSMENT"

# 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.

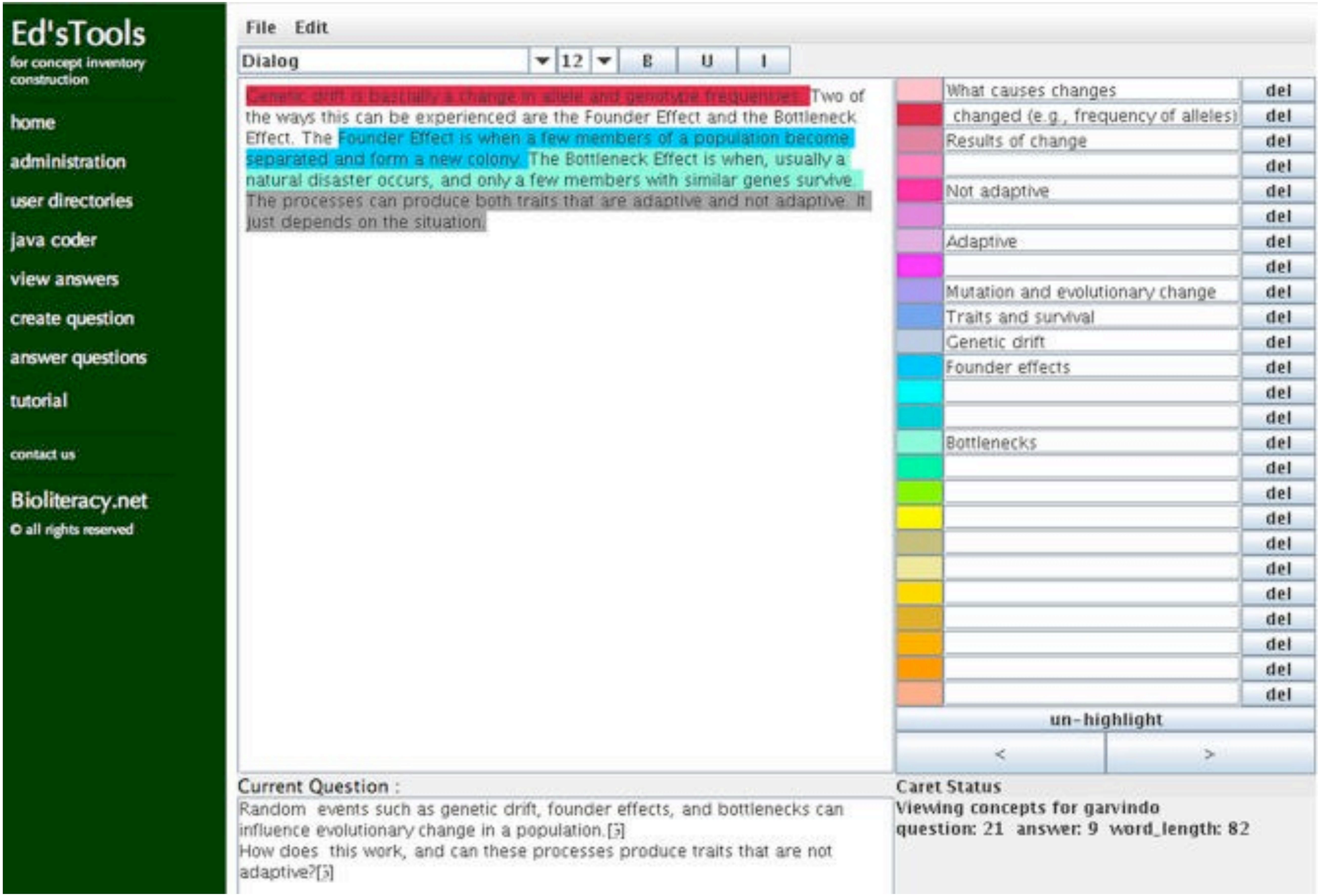
Text

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


BCI word cloud



Thursday, June 7, 12


Ed'sTools
for concept inventory construction
home
administration
user directories
java coder
view answers
create question
answer questions
tutorial
contact us
Bioliteracy.net
© all rights reserved
File Edit
Dialog
12
B
U
I
Genetic drift is bascially a change in allele and genotype frequencies. Two of the ways this can be experienced are the Founder Effect and the Bottleneck Effect. The Founder Effect is when a few members of a population become separated and form a new colony. The Bottleneck Effect is when, usually a natural disaster occurs, and only a few members with similar genes survive. The processes can produce both traits that are adaptive and not adaptive. It just depends on the situation.
What causes changes
changed (e.g., frequency of alleles)
Results of change
Not adaptive
Adaptive
Mutation and evolutionary change
Traits and survival
Genetic drift
Founder effects
Bottlenecks
del
un-highlight
<
>
Current Question :
Random events such as genetic drift, founder effects, and bottlenecks can influence evolutionary change in a population.[3]
How does this work, and can these processes produce traits that are not adaptive?[3]
Caret Status
Viewing concepts for garvindo
question: 21 answer: 9 word_length: 82

# Molecular level thinking

**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 actively be pumped to the right area.
- ❍ e. Random movements would bring it to the ATP synthase.

# Molecular level thinking

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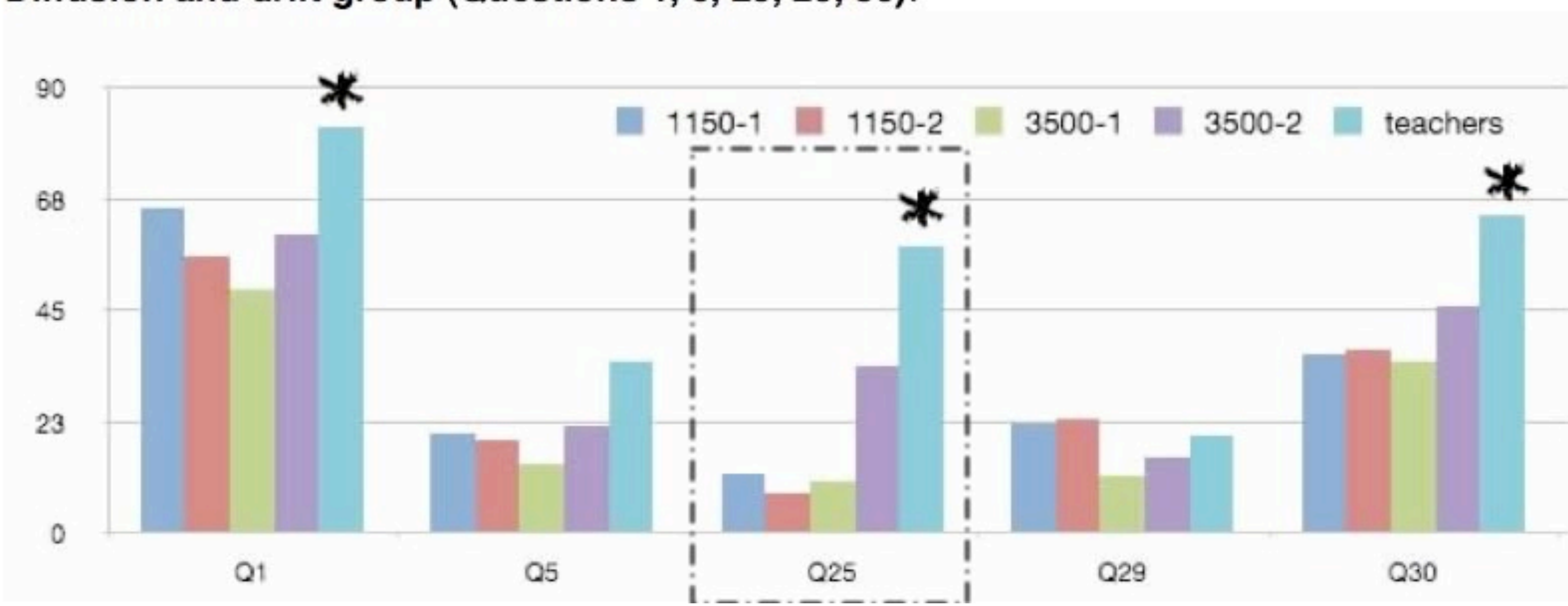
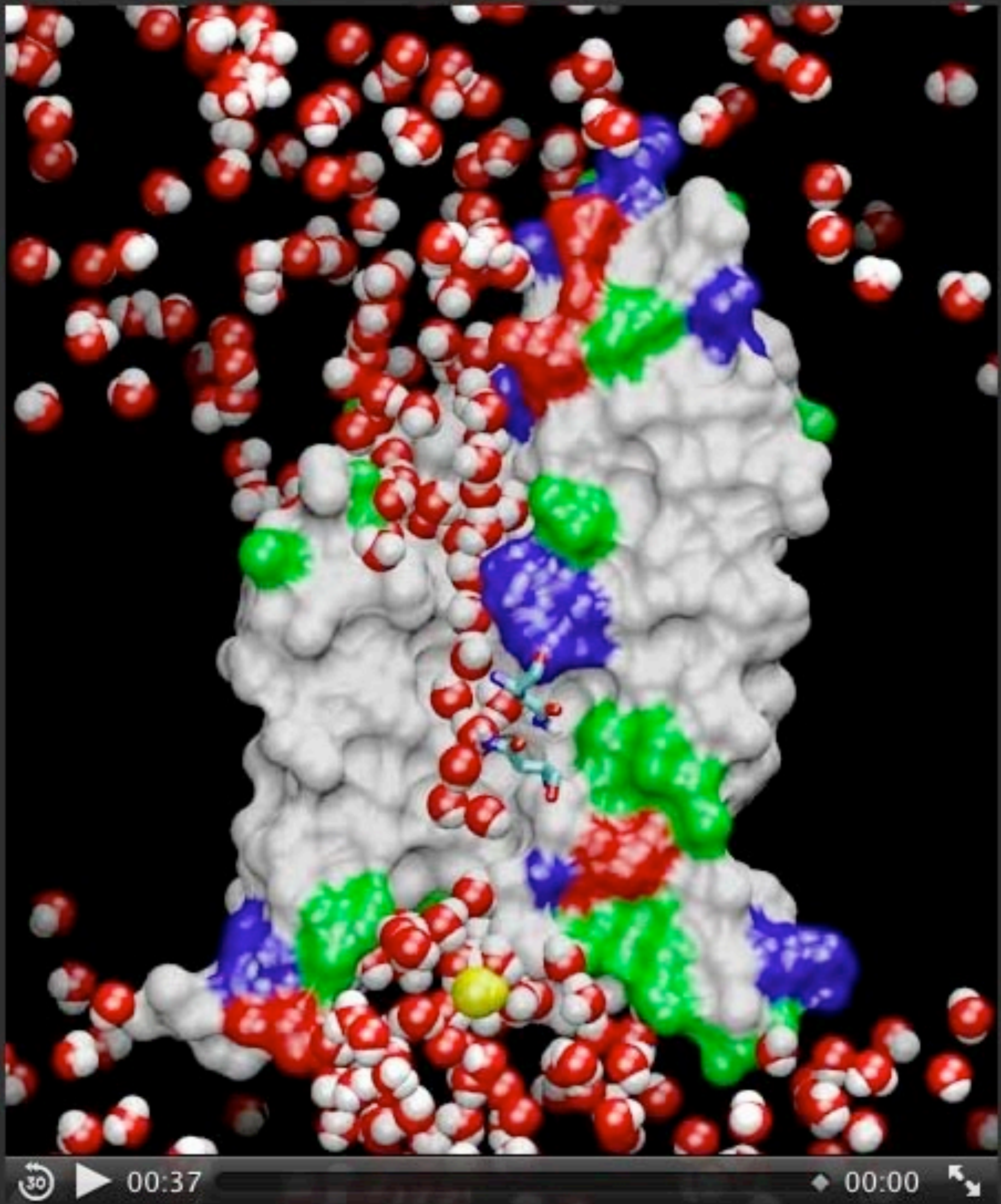
**Diffusion and drift group (Questions 1, 5, 25, 29, 30):**



# Random processes seem impossible




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

# The difficult of randomness

*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

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

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

# The difficult of randomness

Because mutations are random, the **cannot** lead to useful effects; either evolution cannot occur or must require (super natural) guidance!

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Our suggestion:
Address the issue head on, illustrate/emphasize that stochastic processes (however silly they look) "work" at the molecular level.

# What do responses tell us?

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**BCI Q: 23** An individual, "A", displays two distinct traits. A single, but different gene controls each trait. You examine A's offspring, of which there are hundreds, and fin most display either the same two traits displayed by A, or neither trait. There are, however, rare offspring that display one or the other trait, but not both.

A. The genes controlling the two traits are located on different chromosomes.
B. The genes controlling the two traits are located close together on a single chromosome.
C. The genes controlling the two traits are located at opposite ends of the same chromosome.

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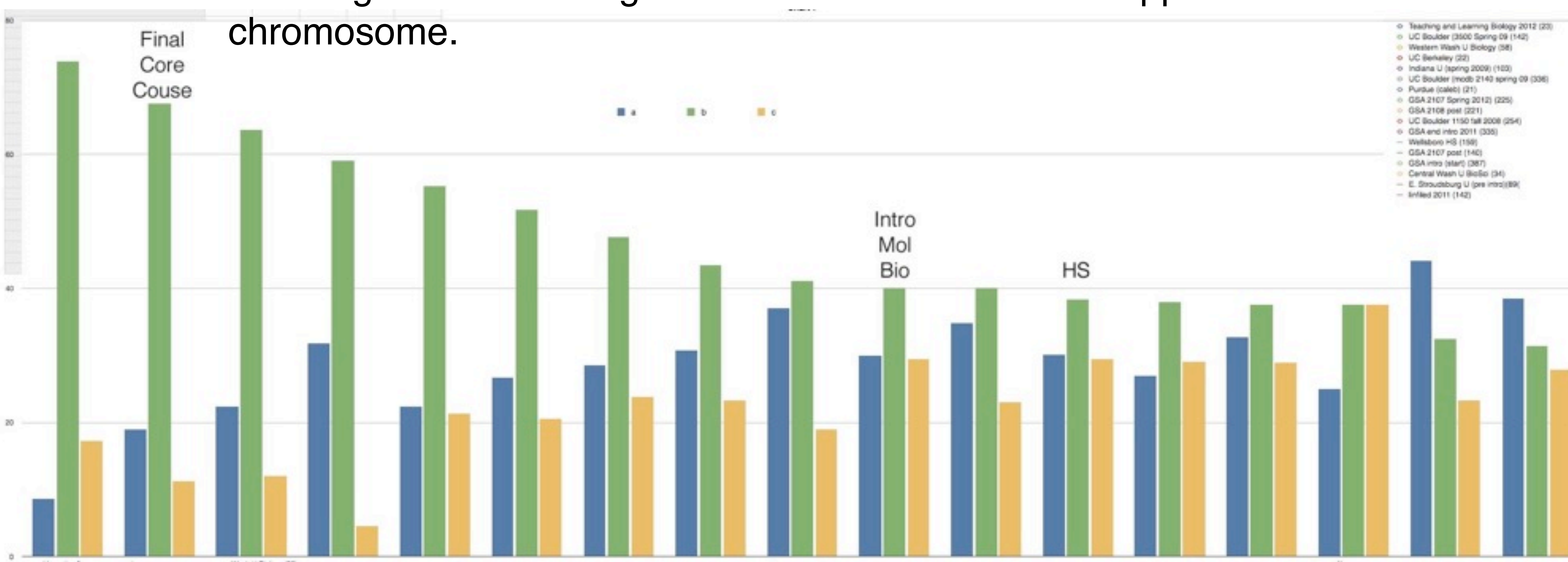

Leaves unanswered, whether students understand why (biologically) gene linkage is important?

# Look at other student thinking other ways....

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Using more informative instruments:

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graphic analysis (Trujillo et al 2012. BAMBED **40**:100)

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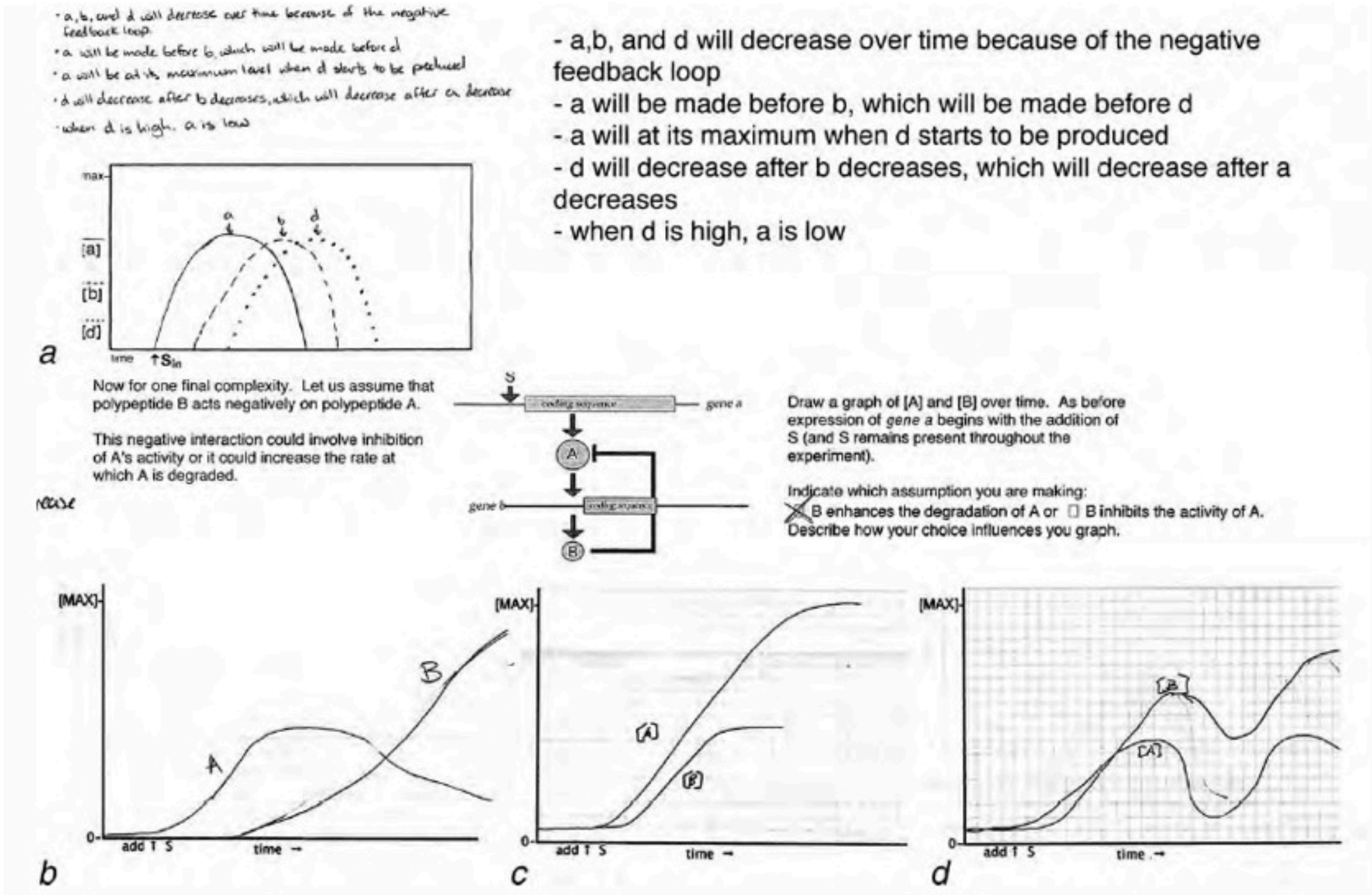
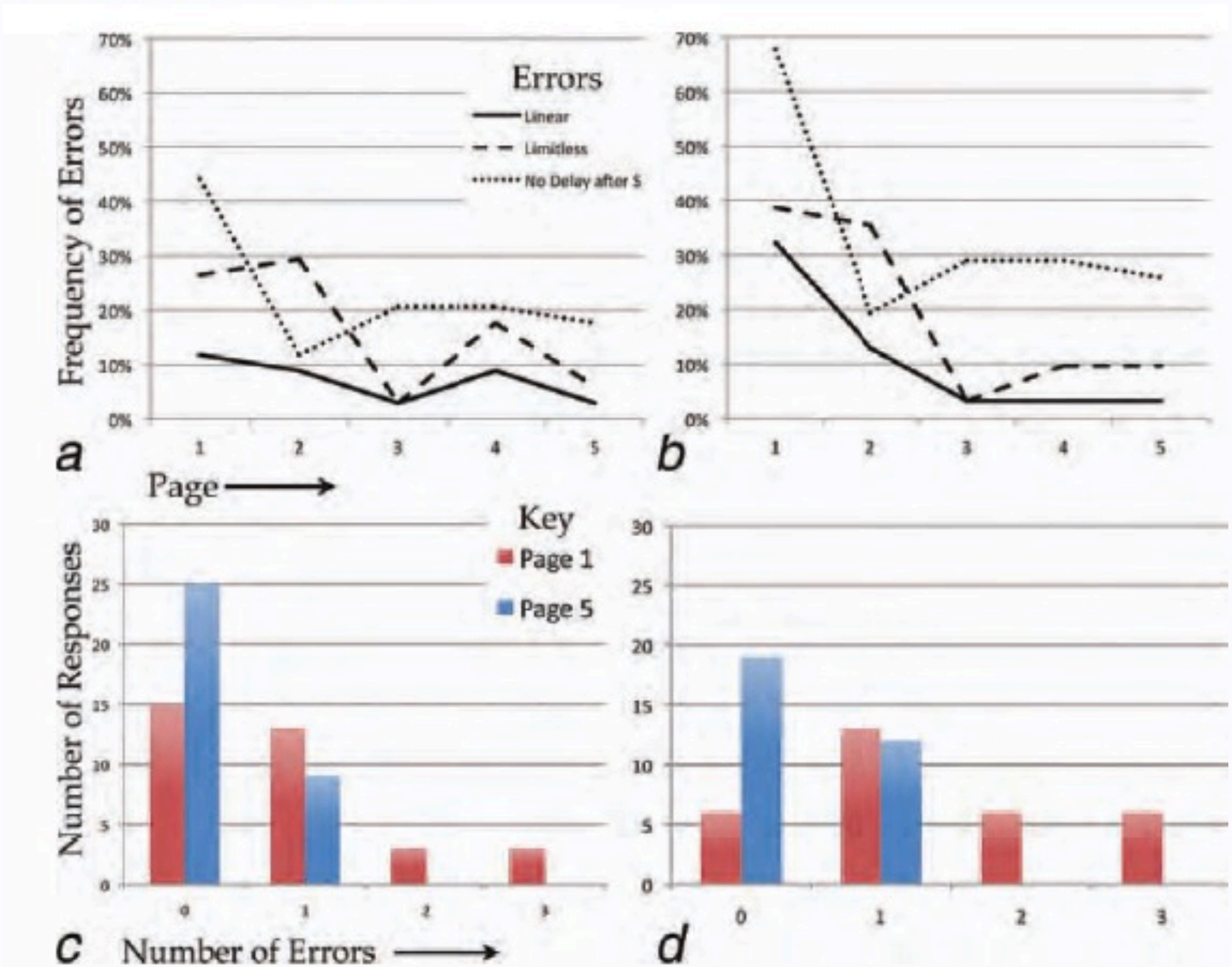
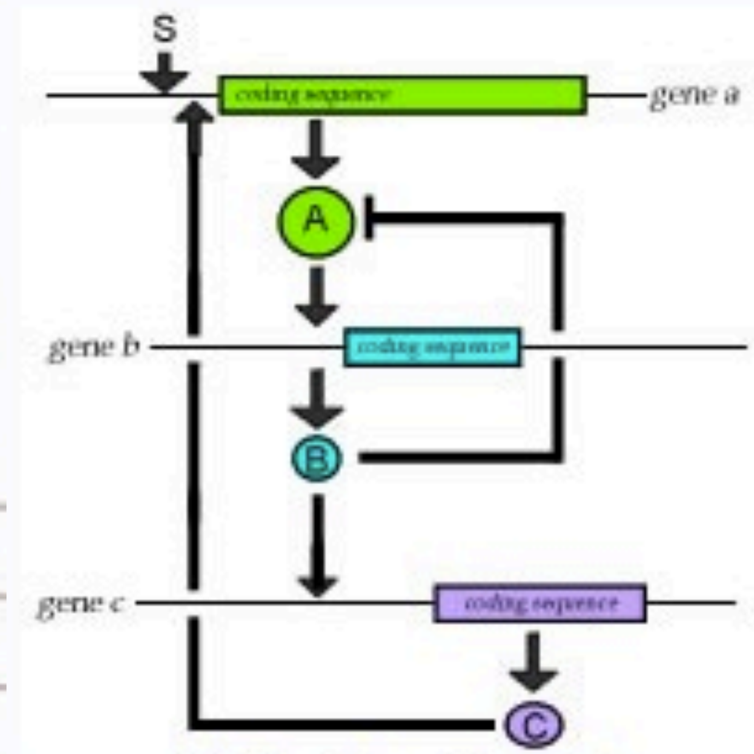


# Discovering student thinking ...

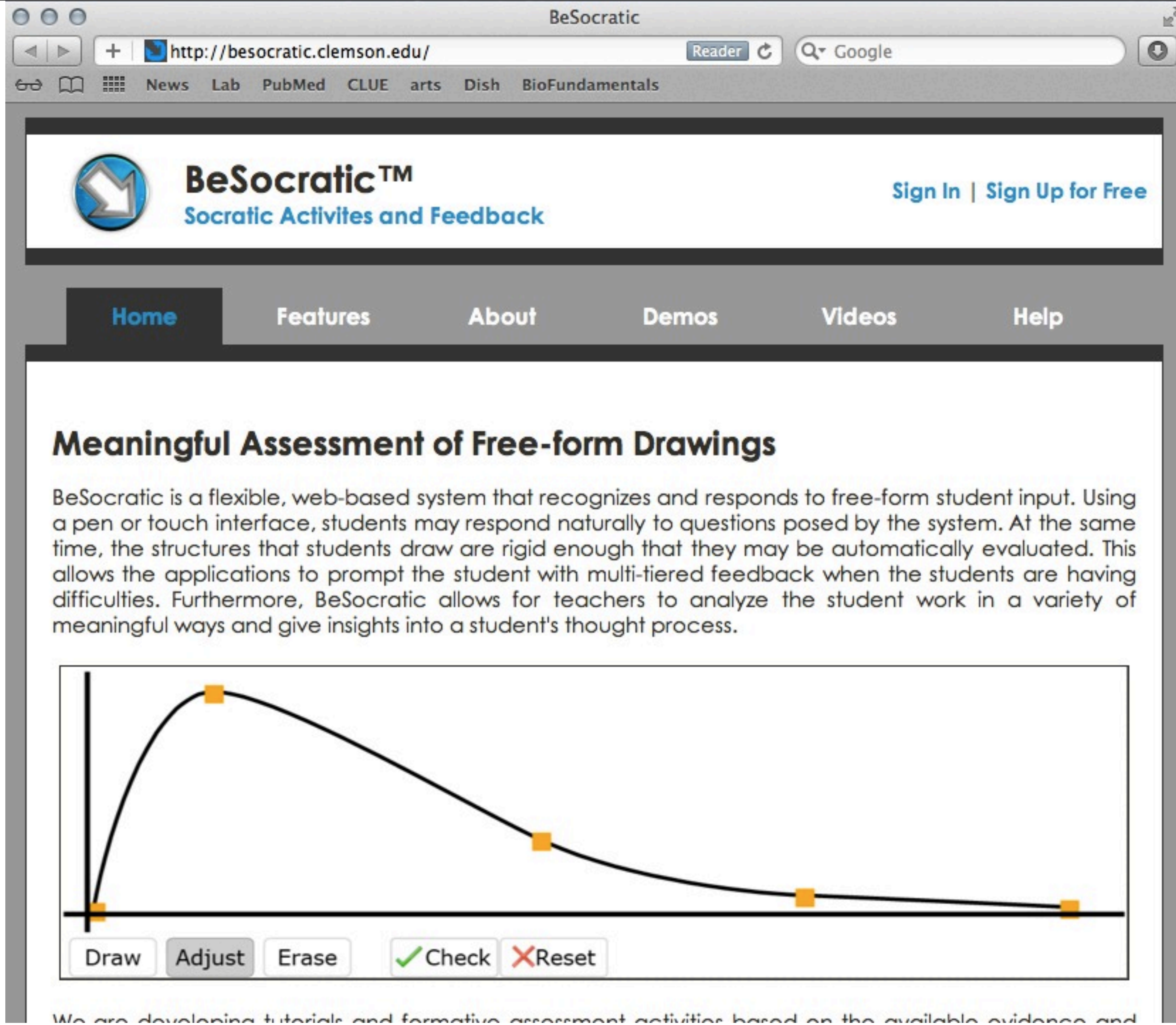
**Thinking about networks:**




**Go! to the tutorial**

Discussed further by Melanie Cooper (tomorrow)



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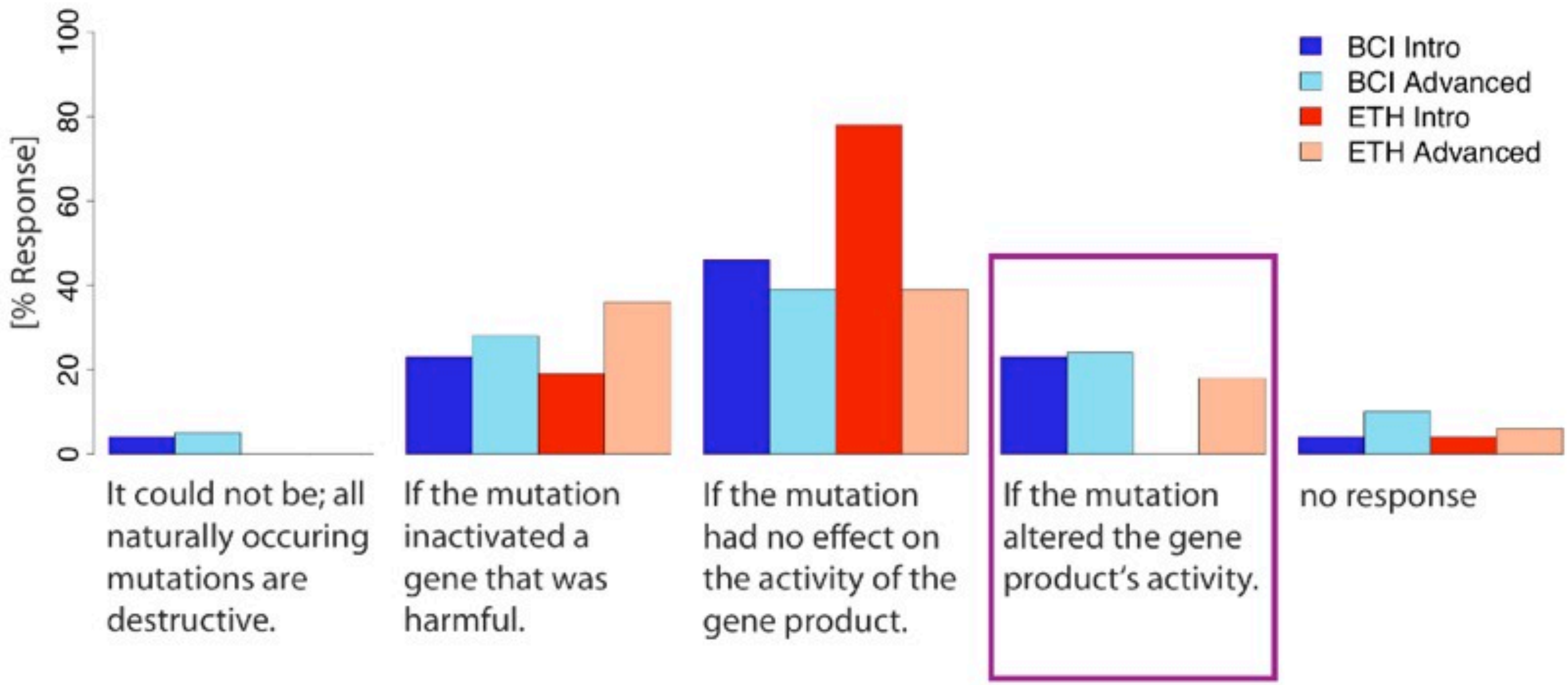
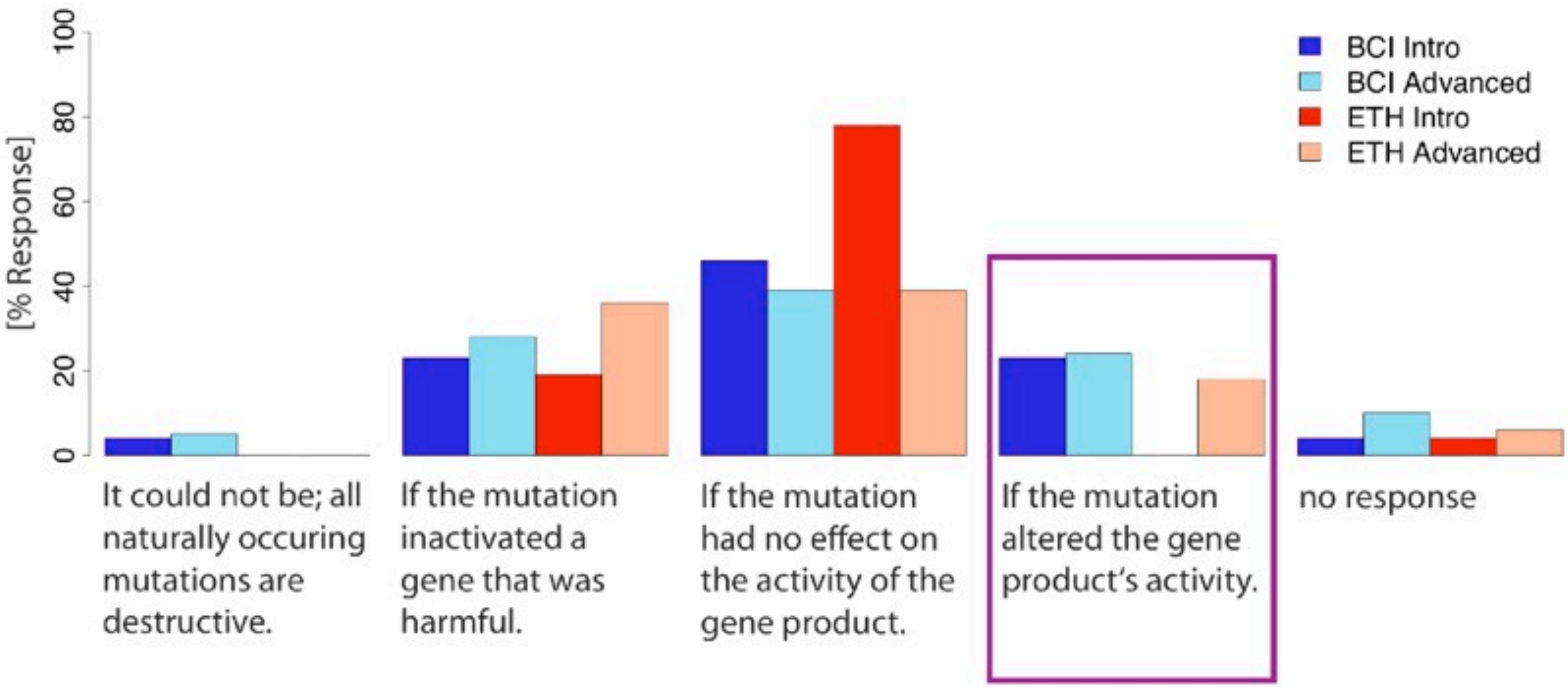


# Look at other student thinking other ways....




Using more informative instruments

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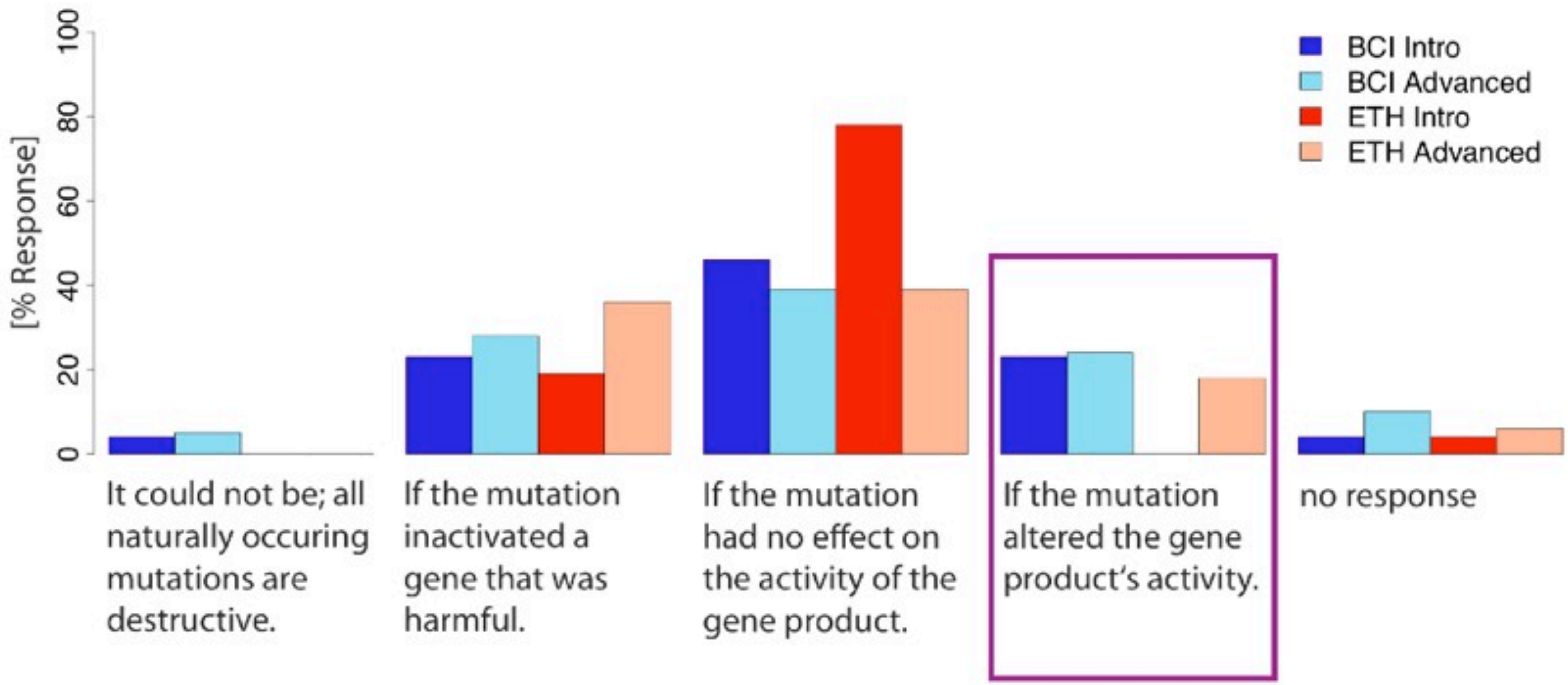


Using more informative instruments

- textual analysis (Hensen et al 2012. Biology Open, online)

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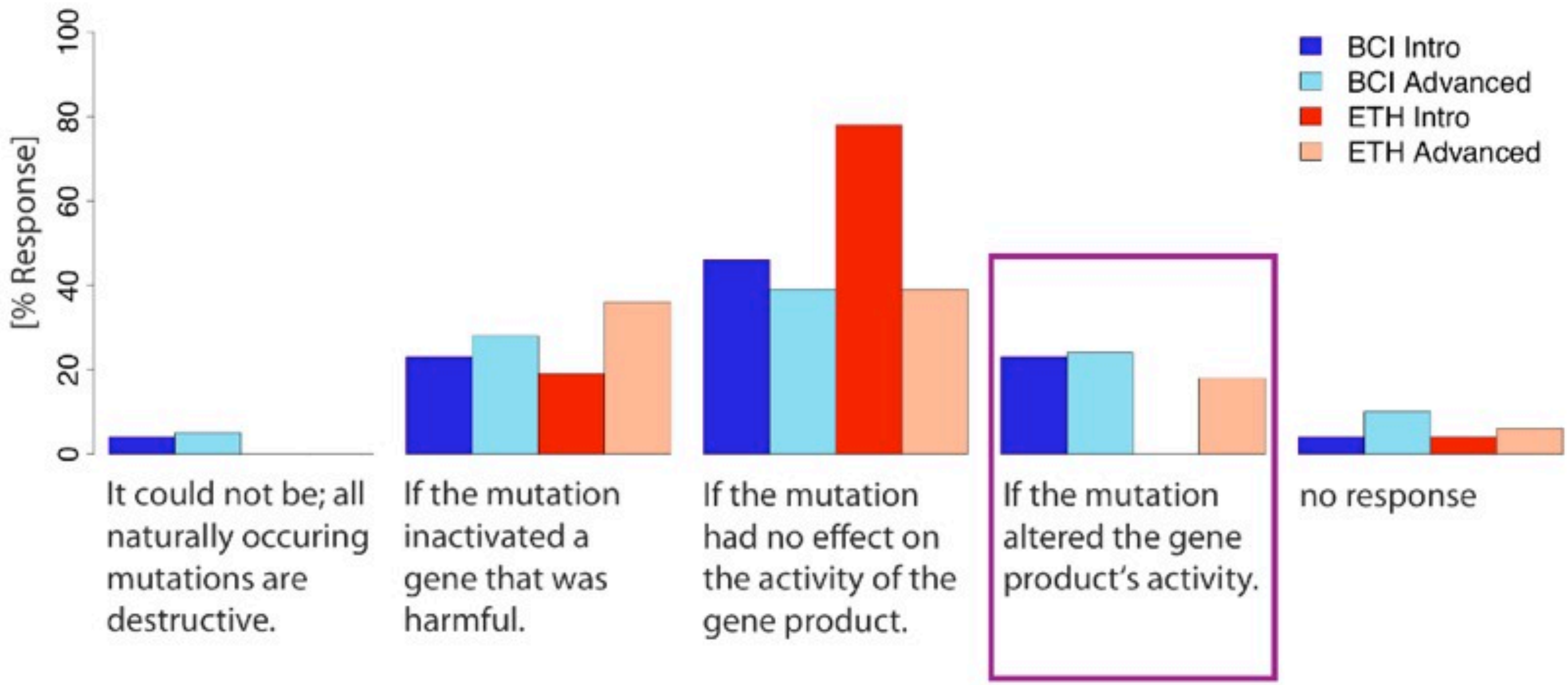


Using more informative instruments

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# Provide context through Muller's morphs

(1932). Further studies on the nature and causes of gene mutations. Sixth Int. Cong. Genet. 1, 213–255.

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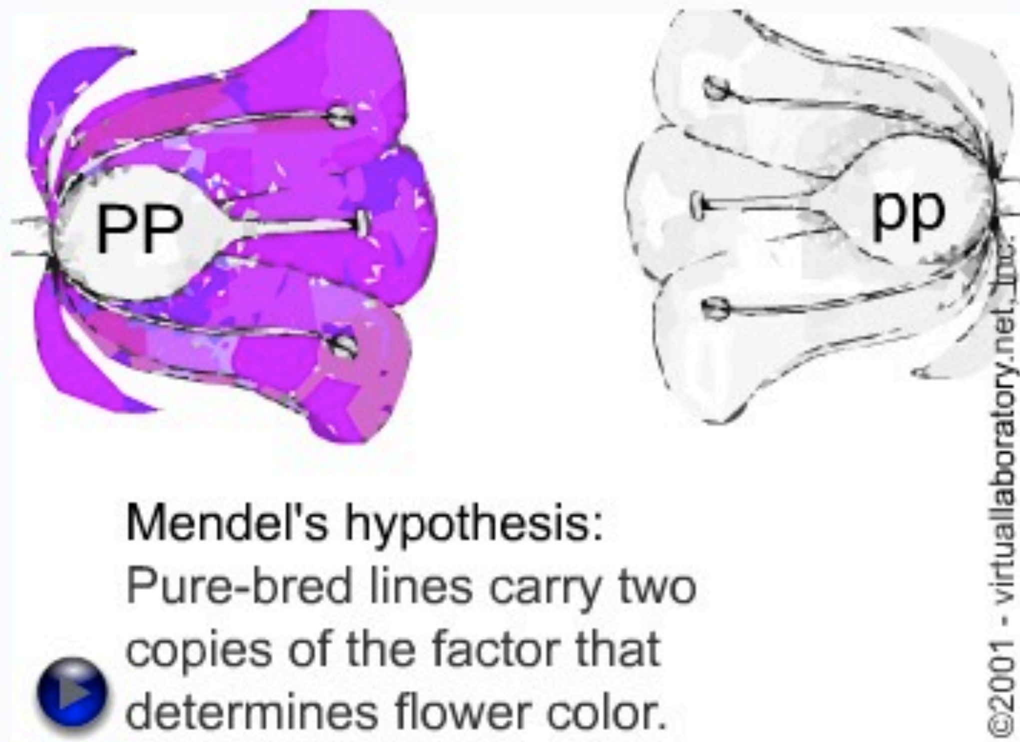
(1932). Further studies on the nature and causes of gene mutations. Sixth Int. Cong. Genet. 1, 213–255.

**Mendel's Factors & Muller's mutations – page 1of 9**

As you almost certainly already know (and can review here), in the 1800's Mendel deduced the existence of genetic factors (which we now know as genes).

These factors are passed unaltered from parent to offspring - but importantly, not all factors held by a parent are transmitted (note on simplifications).

Each parent has two copies of each gene, but one and only one copy is transmitted to any particular offspring. Which copy is transmitted is random (stochastic).

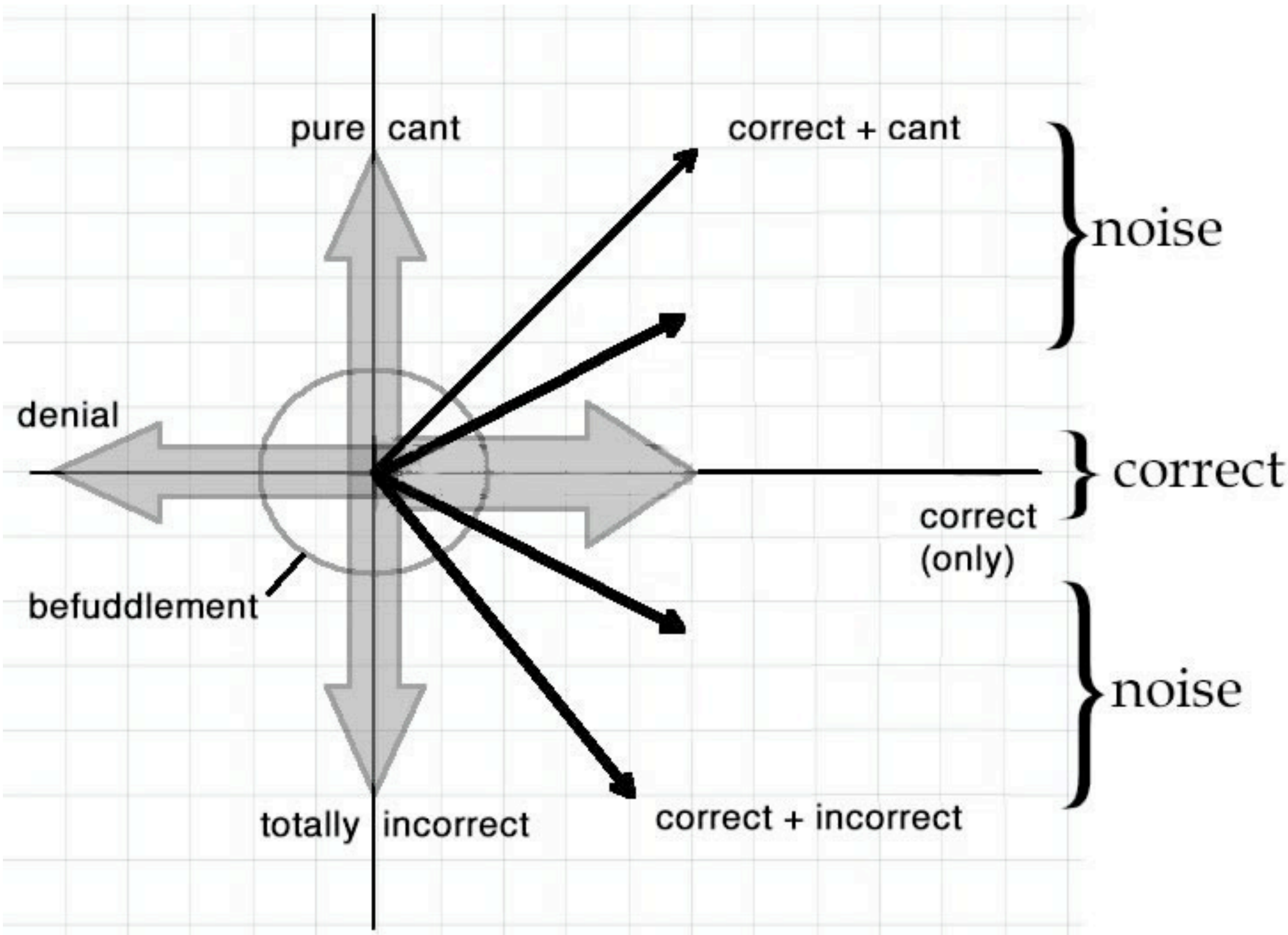



As you answer these questions, remember, there is rarely a single correct answer.

**What did Mendel know about the physical nature of his factors?**

Submit/Next

# Coding student responses




*Henson, Cooper & Klymkowsky. 2012. Turning randomness into meaning at the molecular level using Muller's morphs. Biology Open, in press.*

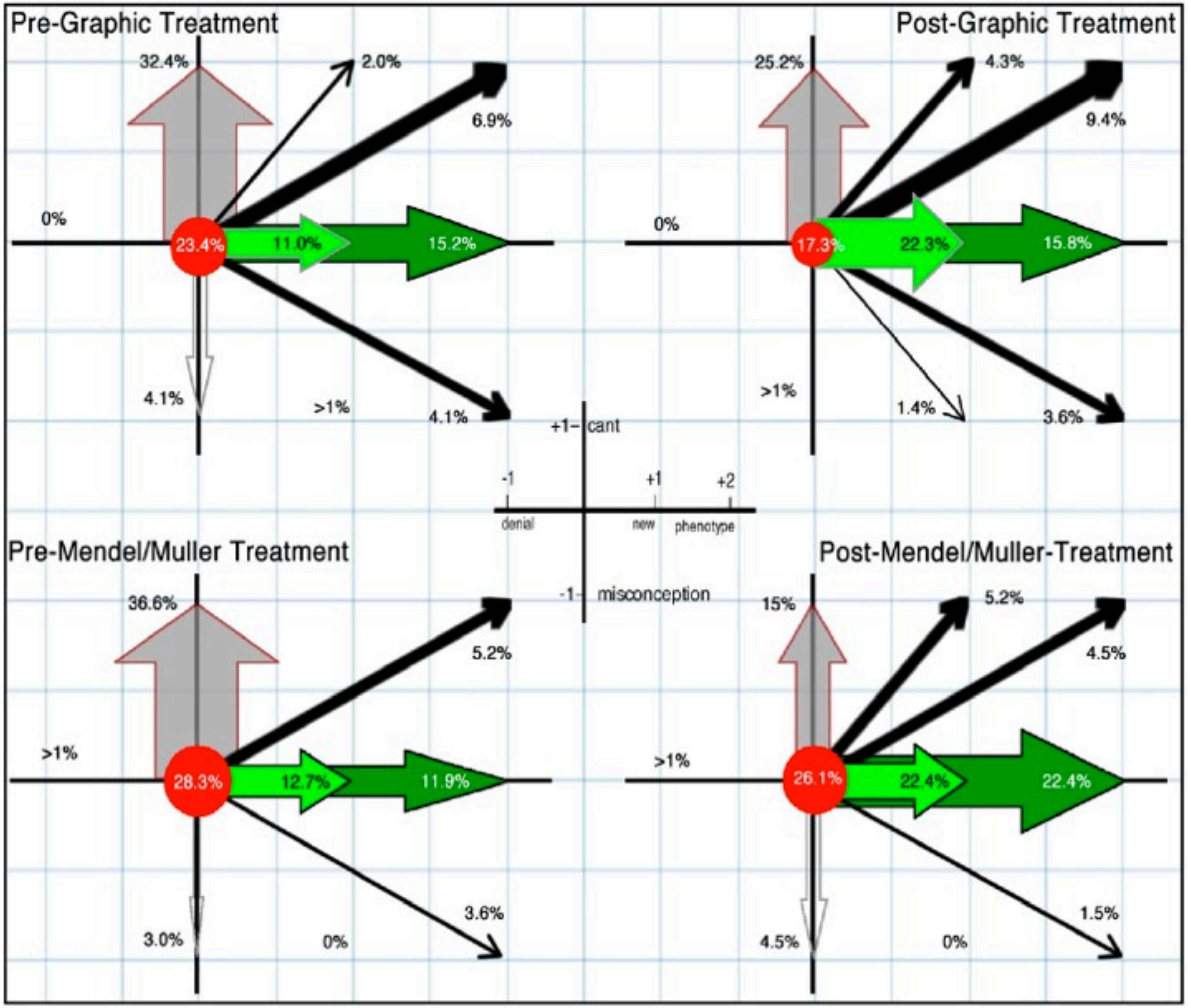



**Fig. 3. Changes in student thinking.** Students were asked to work through either the Graphical Thinking (top panels) or the Mendel/Muller (bottom panels) activities in groups. Student responses to the "How might a mutation be creative?" question pre- (left panels) and post- (right panels) treatment were analyzed.

*Henson, Cooper & Klymkowsky. 2012. Turning randomness into meaning at the molecular level using Muller's morphs. Biology Open, in press.*

# caveats on concept inventories (multiple choice tests)

"The puzzling conclusion is that although individual FCI responses are not reliable, the FCI total score is highly reliable."

Lasry et al., 2011. Am. J. Phys **79**:909-912

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"The puzzling conclusion is that although individual FCI responses are not reliable, the FCI total score is highly reliable."

"This study confirms that the total FCI score reliably measures a single concept, although our analysis is silent as to the nature of this concept."

Lasry et al., 2011. Am. J. Phys **79**:909-912

The under appreciated pitfalls of various instruments (channeling Michael Whitman)

# The under appreciated pitfalls of various instruments (channeling Michael Whitman)

The story was always the same: our ability to predict performance at the school was negligible. Our forecasts were better than blind guesses, but not by much. - Daniel Kahneman

**WYSIATI**: "What you see is all there is."

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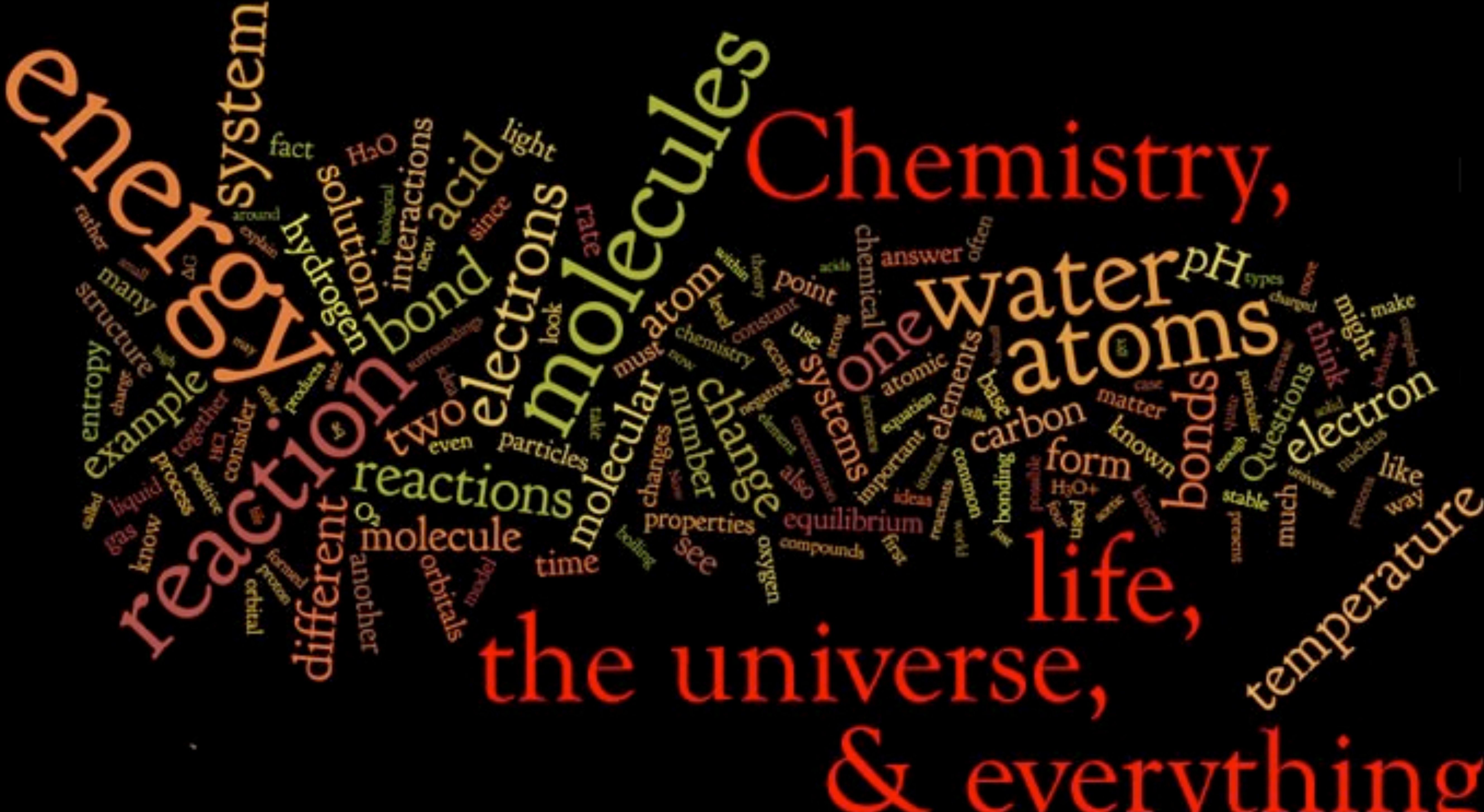
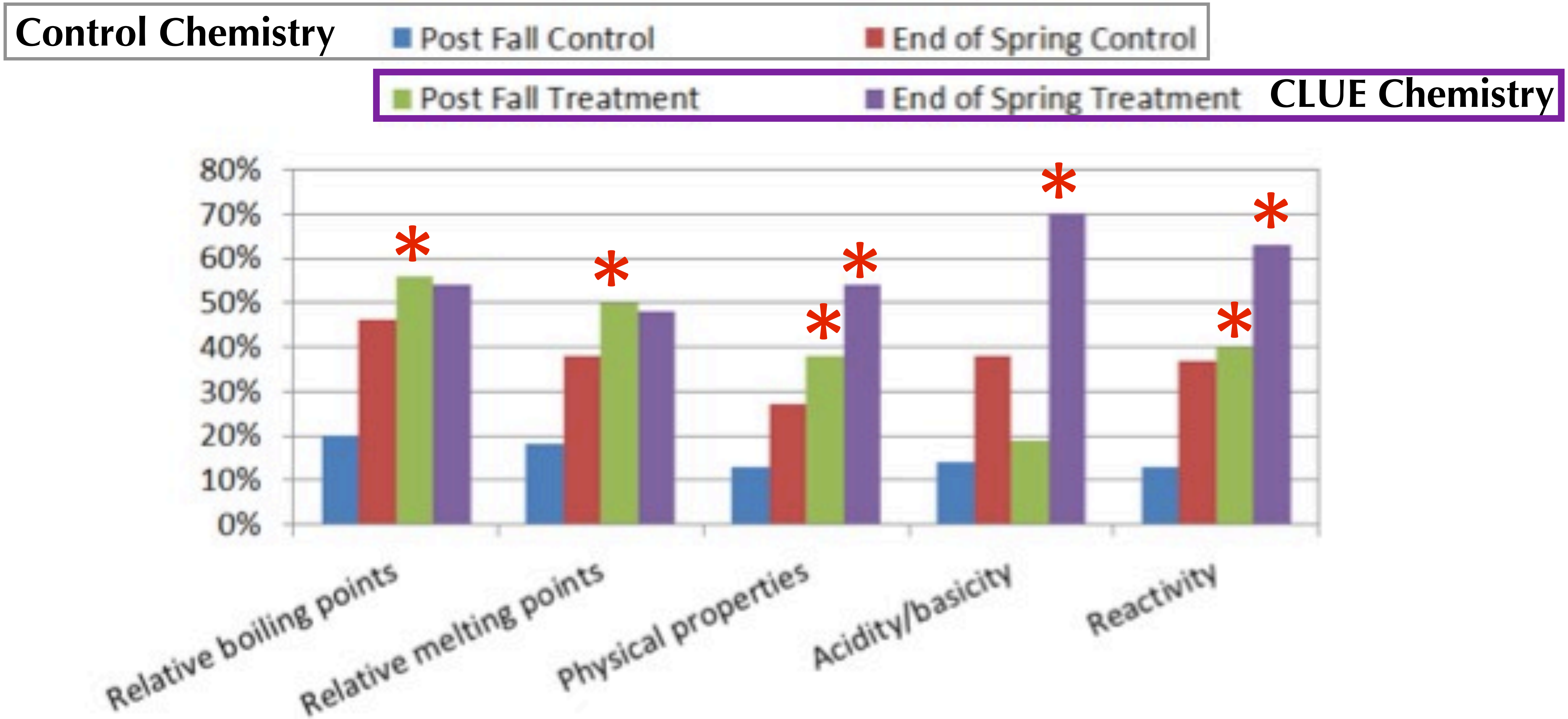
**Simple check:**
Ask students to explain why "incorrect" choices are wrong.



# Chemistry, life, the universe, & everything

Melanie M. Cooper & Michael W. Klymkowsky

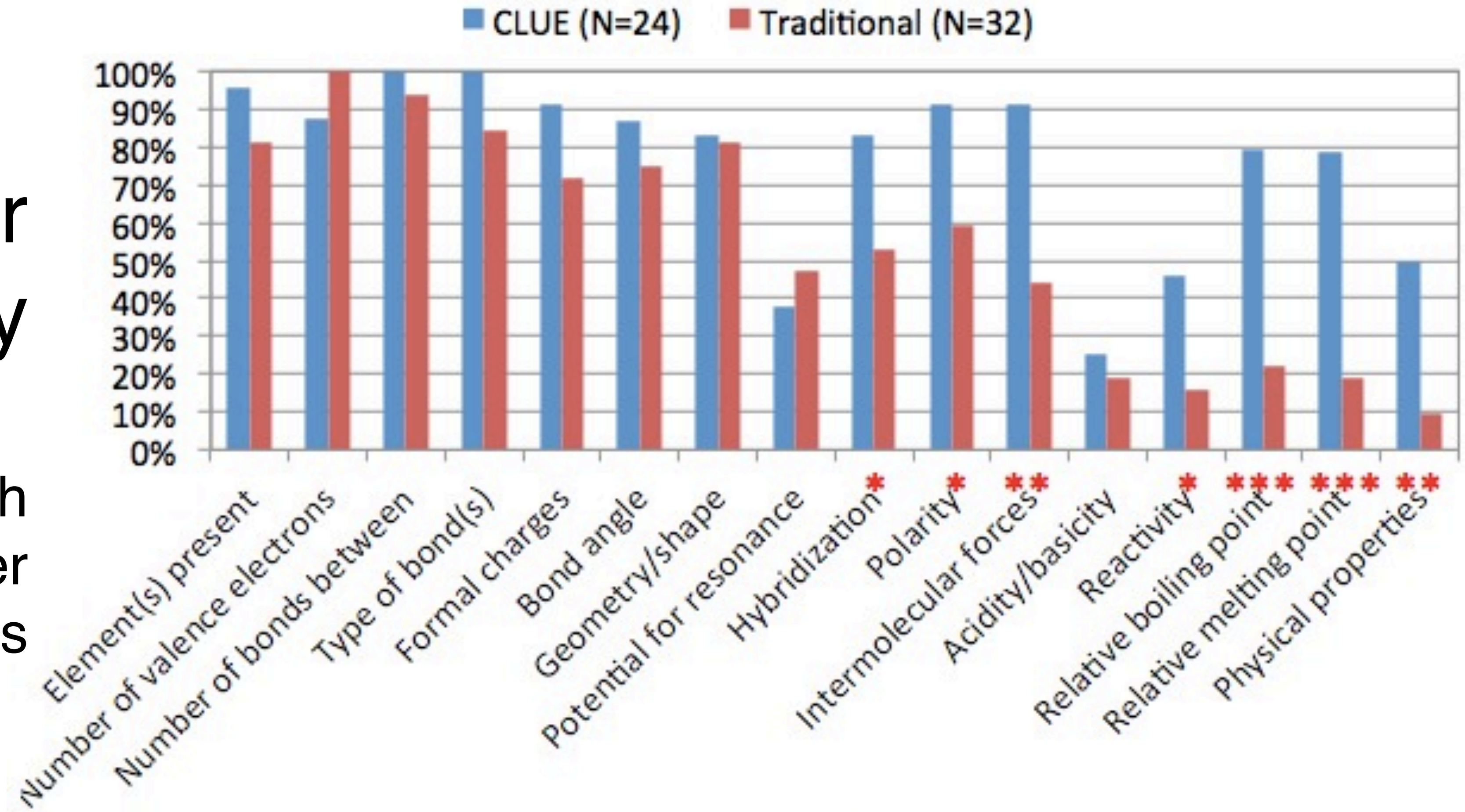



| Chemical Formula | Post Fall Control | Post Fall Treatment | p-value | End of Spring Control | End of Spring Treatment | p-value |
|---|---|---|---|---|---|---|
| Relative boiling points | 20% | 56% | < .001 | 46% | 54% | .512 |
| Relative melting points | 18% | 50% | < .001 | 38% | 48% | .311 |
| Physical properties | 13% | 38% | < .001 | 27% | 54% | .003 |
| Acidity/basicity | 14% | 19% | .408 | 38% | 70% | < .001 |
| Reactivity | 13% | 40% | < .001 | 37% | 63% | .005 |

*Development and Assessment of a Molecular Structure and Properties Learning Progression*, Cooper, Underwood, Hilley & Klymkowsky, "in press"

# After first semester of intro. chemistry

n.b. started with 90 in each group and followed them over two years




Effect Size: 0.28, 0.32, 0.46, 0.29, 0.53, 0.57, 0.41

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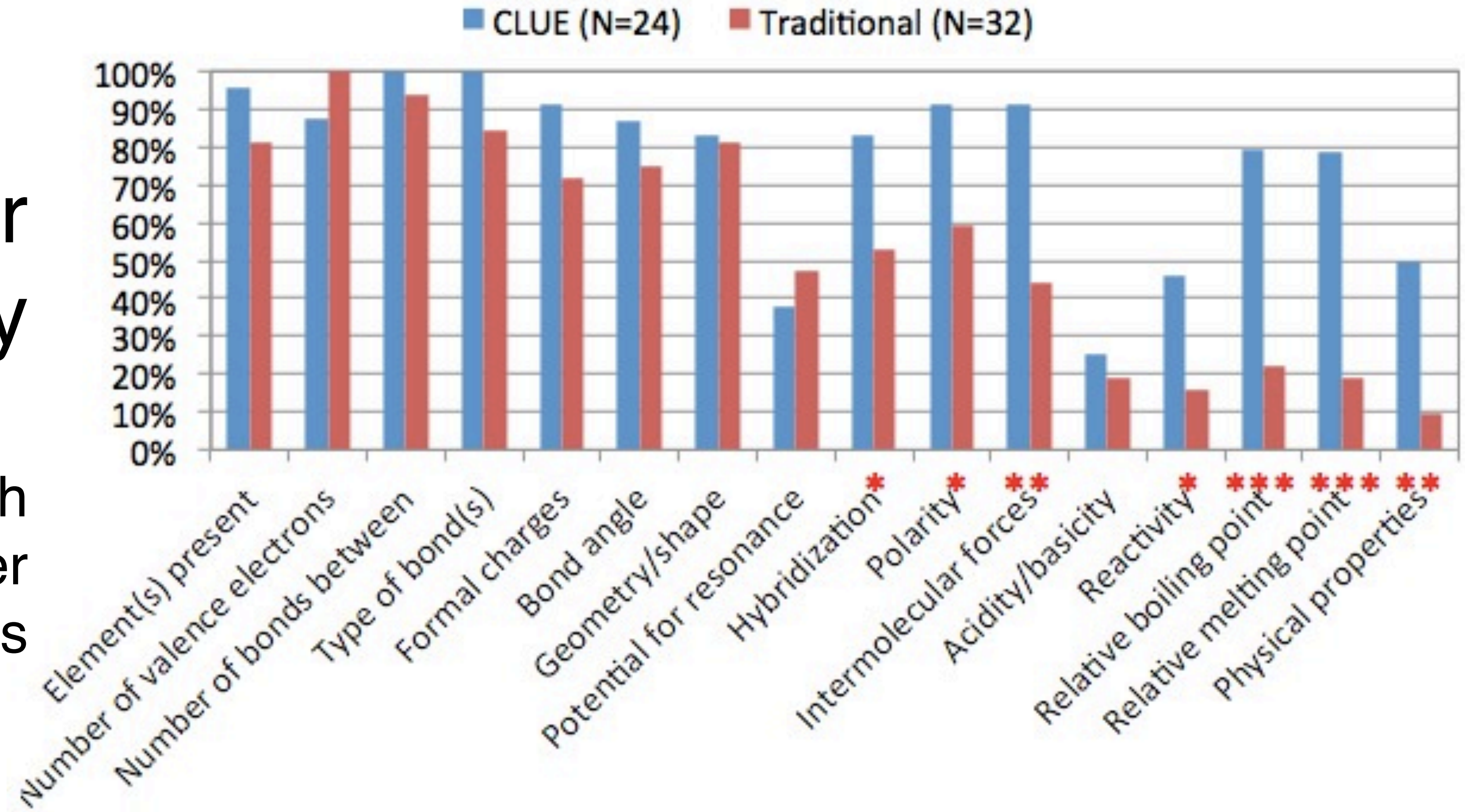
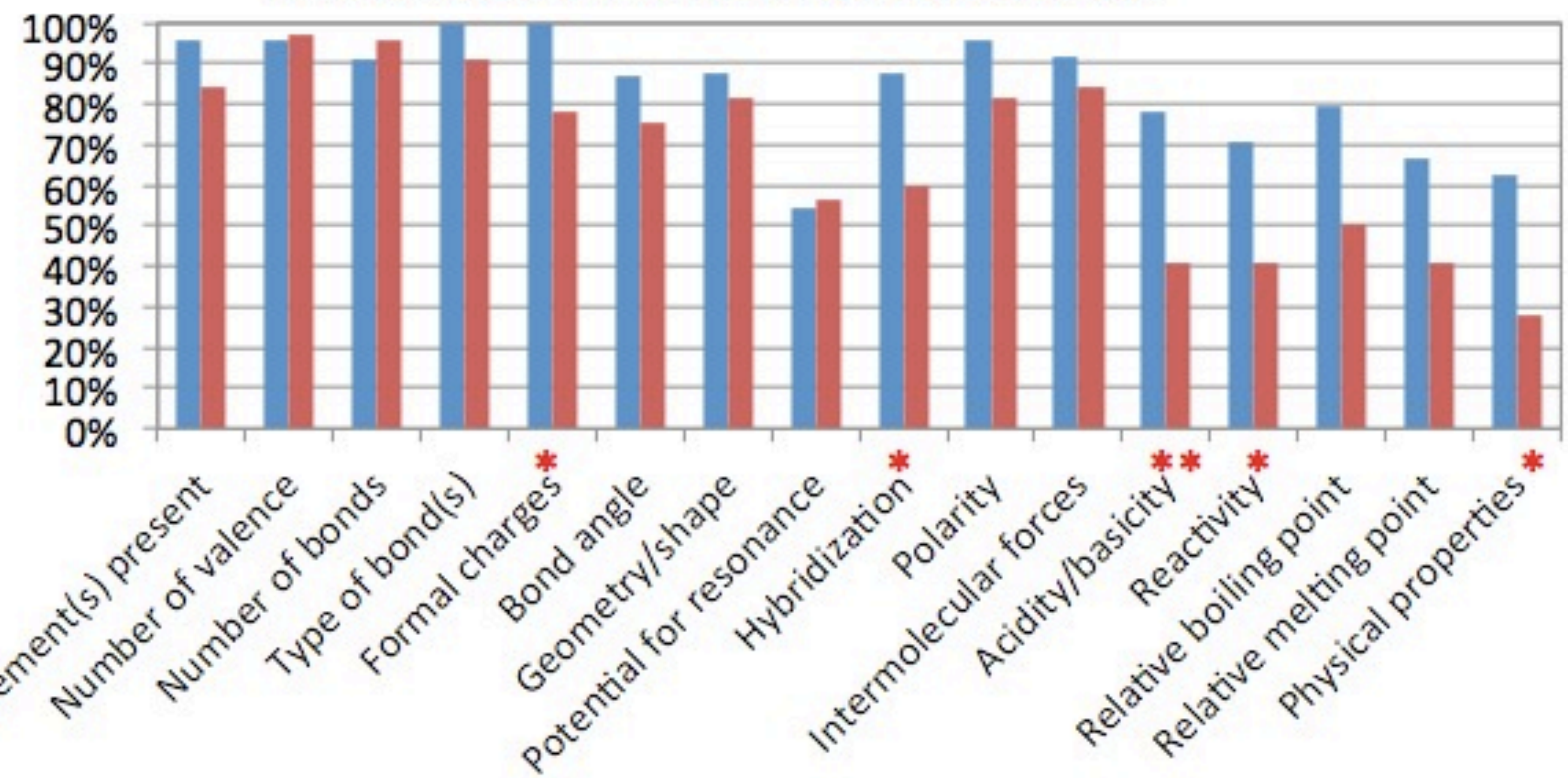


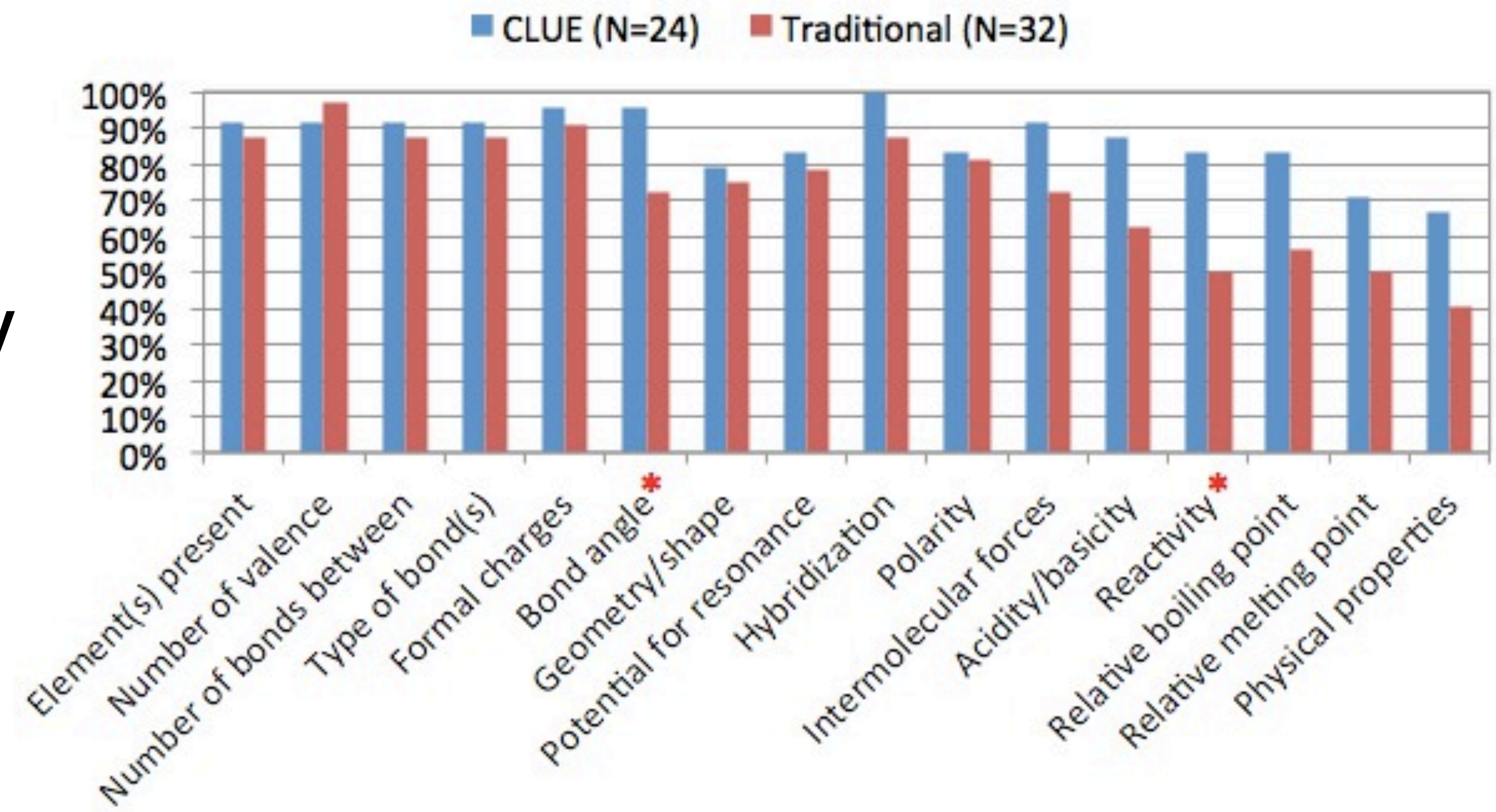

Effect Size: 0.28, 0.32, 0.46, 0.29, 0.53, 0.57, 0.41

After second semester of intro. chemistry



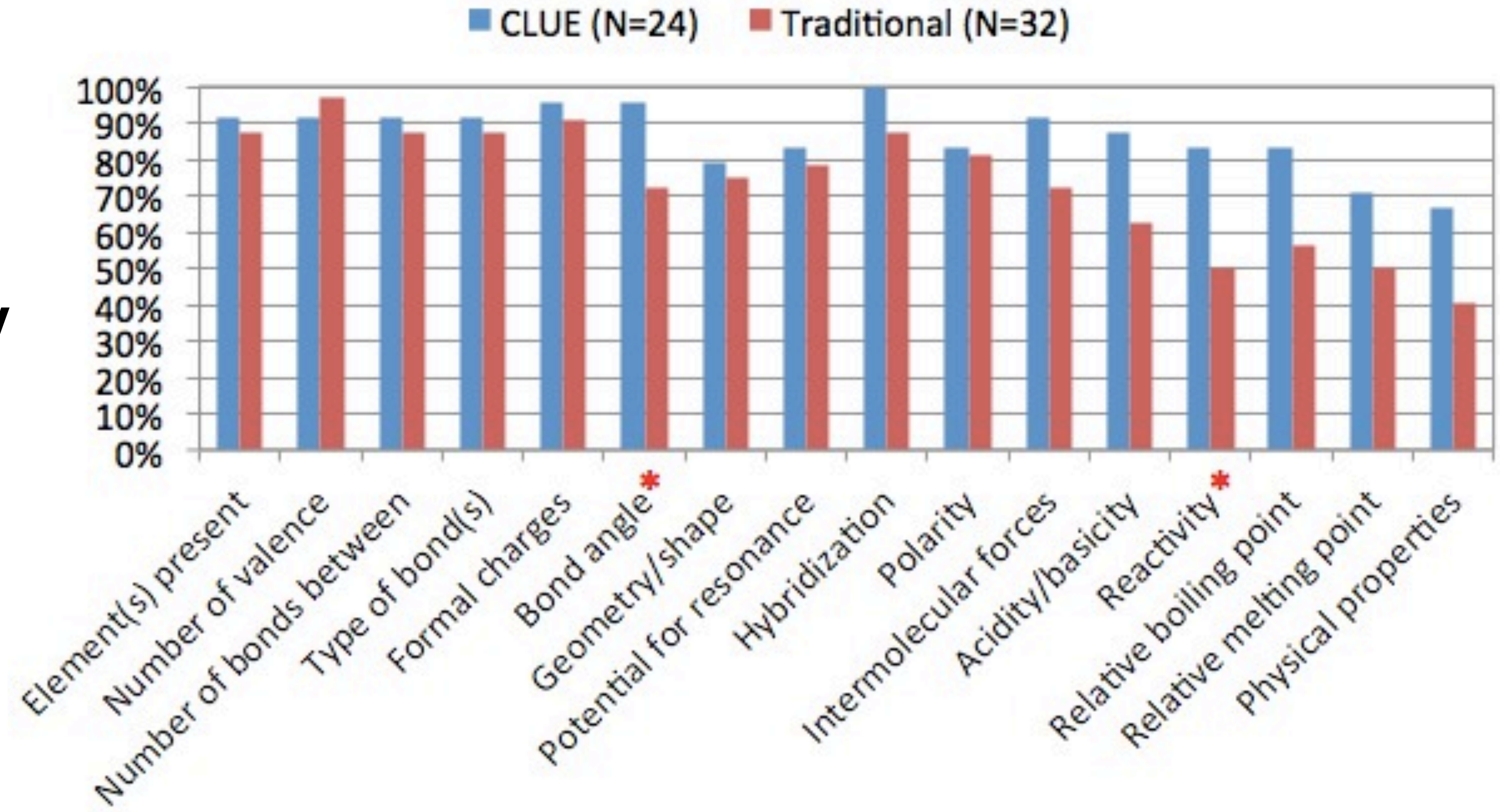

Effect Size: 0.27, 0.27, 0.35, 0.26, 0.31

After one semester of organic chemistry



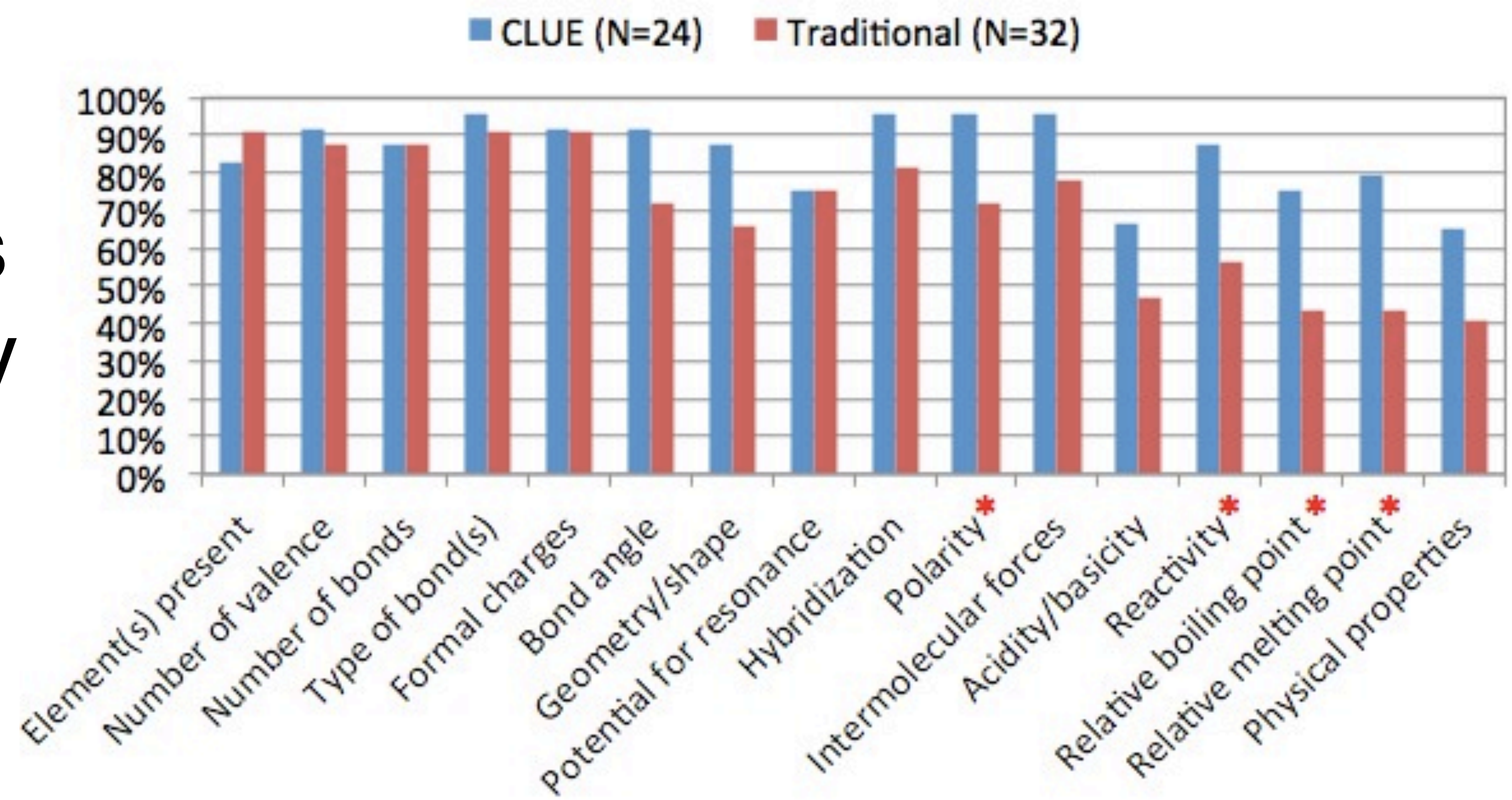

Effect Size: 0.26, 0.30, 0.28, 0.32

After one semester of organic chemistry




Effect Size: 0.26, 0.30, 0.28, 0.32

After two semesters of organic chemistry




Effect Size: 0.26, 0.30, 0.28, 0.32

## Summary:

We have evidence that coherently designed curriculum are more effective in promoting student learning.

Course/curriculum need to be:

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**rigorous**
**coherent**
**realistic**