Unrecognized conceptual hurdles to understanding evolutionary biology ... and some of their physiochemical roots.

Mike Klymkowsky

Professor, Molecular, Cellular & Developmental Biology
Co-Director, CU Teach Science/Math Teacher Recruitment & Certification Program

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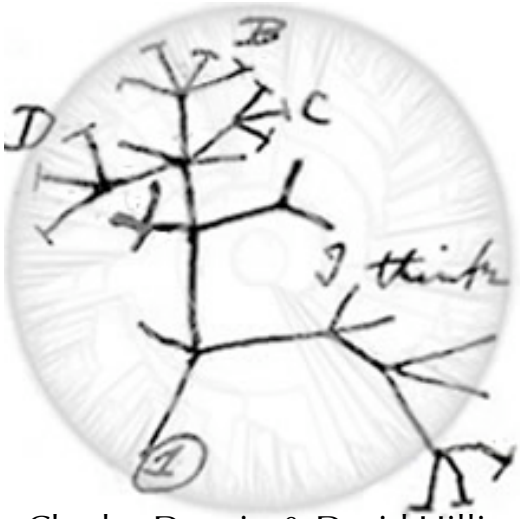


Charles Darwin & David Hillis

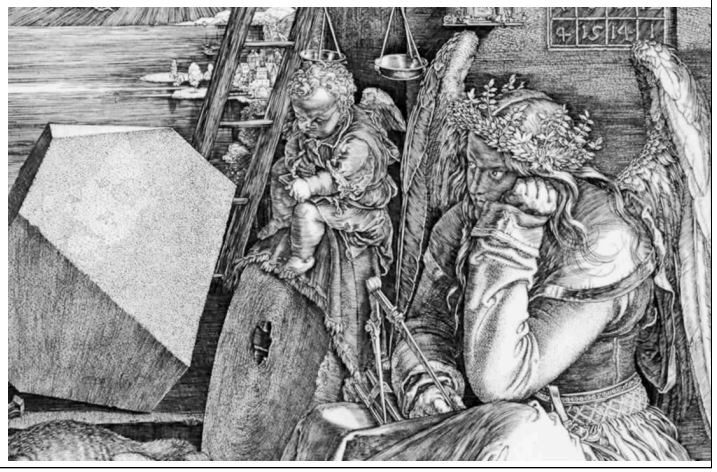
google: biofundamentals, bioliteracy, CU Teach

Why are scientific ideas difficult to grasp / apply / accept?

☑ Many are deeply counter-intuitive

These include ...

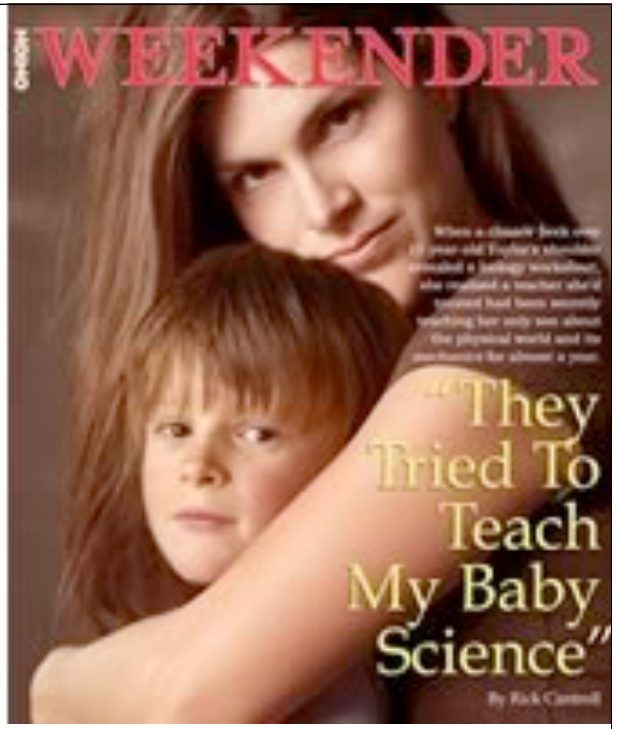
- ☐ The Laws of Thermodynamics
- ☐ Atomic theory / quantum mechanics
- ☐ Entropy (in general)
- ☐ The age (and size) of the universe

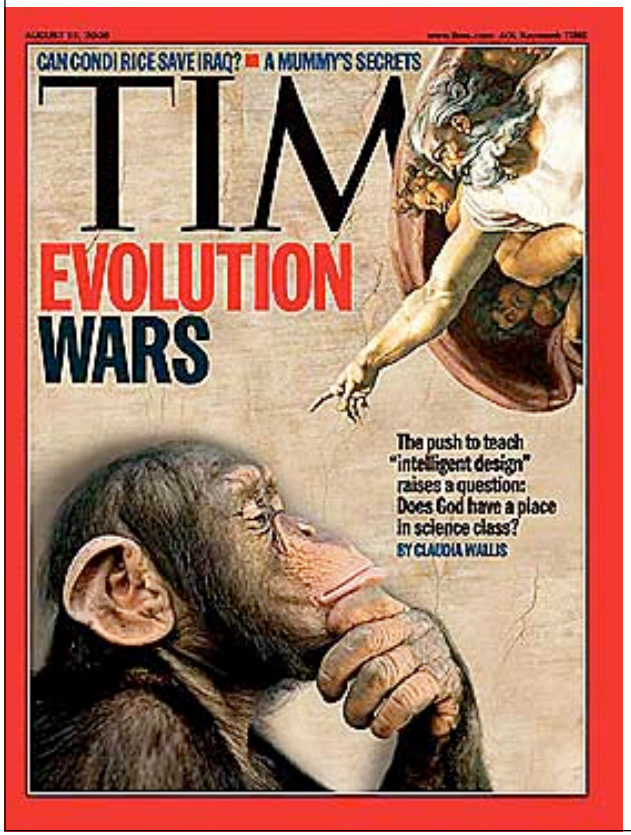


Not to mention

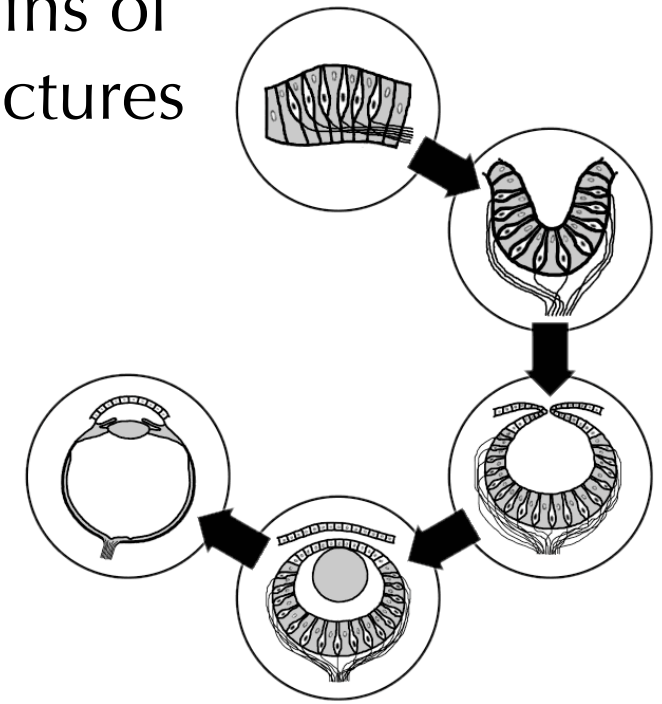
physiochemical basis of life

cell theory of life



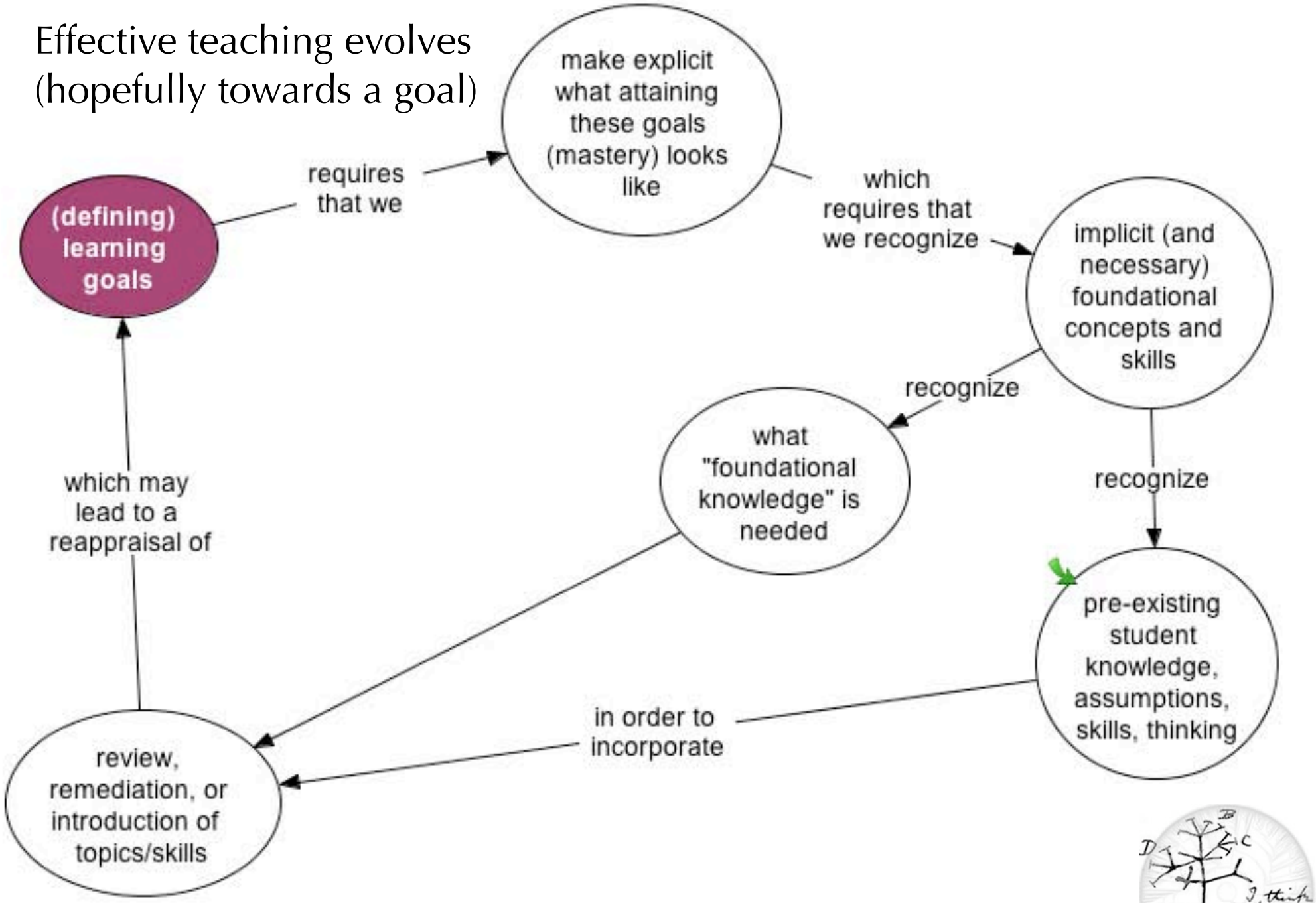


Random origins of complex structures



which can lead to some serious sociocultural ramifications

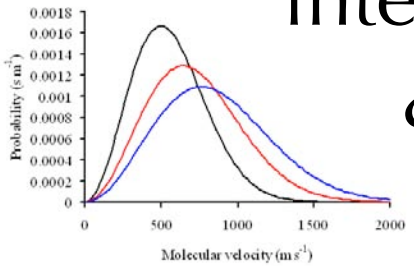
Effective teaching evolves (hopefully towards a goal)



Teaching & learning biology: Furtak & Klymkowsky, UC Boulder 2008
http://www.colorado.edu/MCDB/LearningBiology/

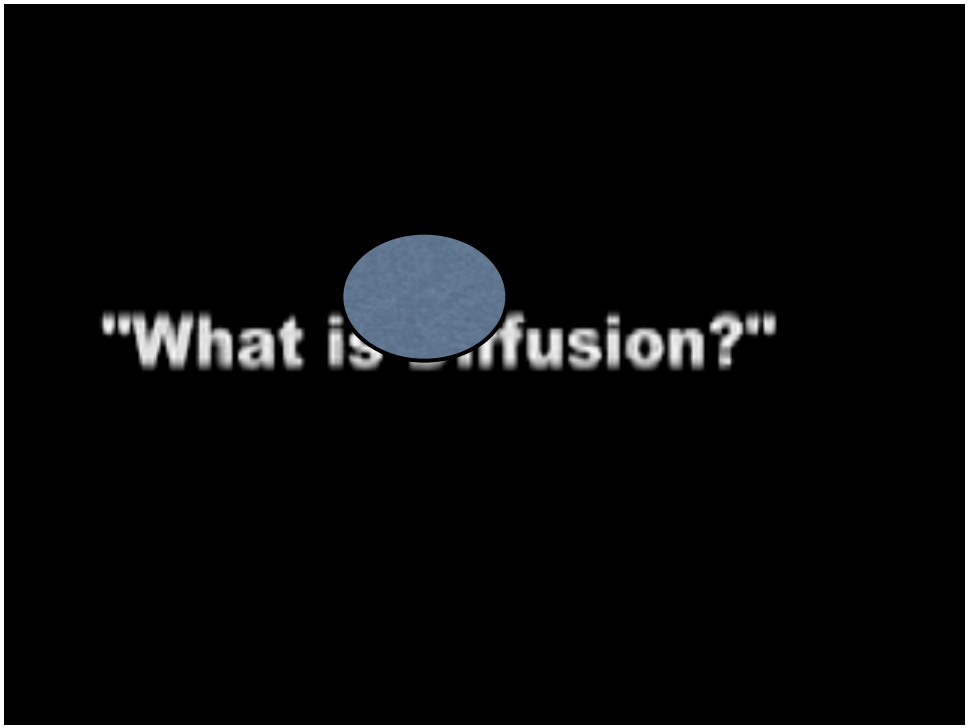
Biology's physiochemical foundations

- Conservation of energy and matter
  - understanding energy and matter
  - when is $e = mc^2$ applicable and when isn't it.
- Laws of Thermodynamics
  - understanding work and entropy
    and the assembly of complex structures
  - kinetic vs potential energy
    molecular movement (diffusion)
    interaction stability, specificity
    & dynamics

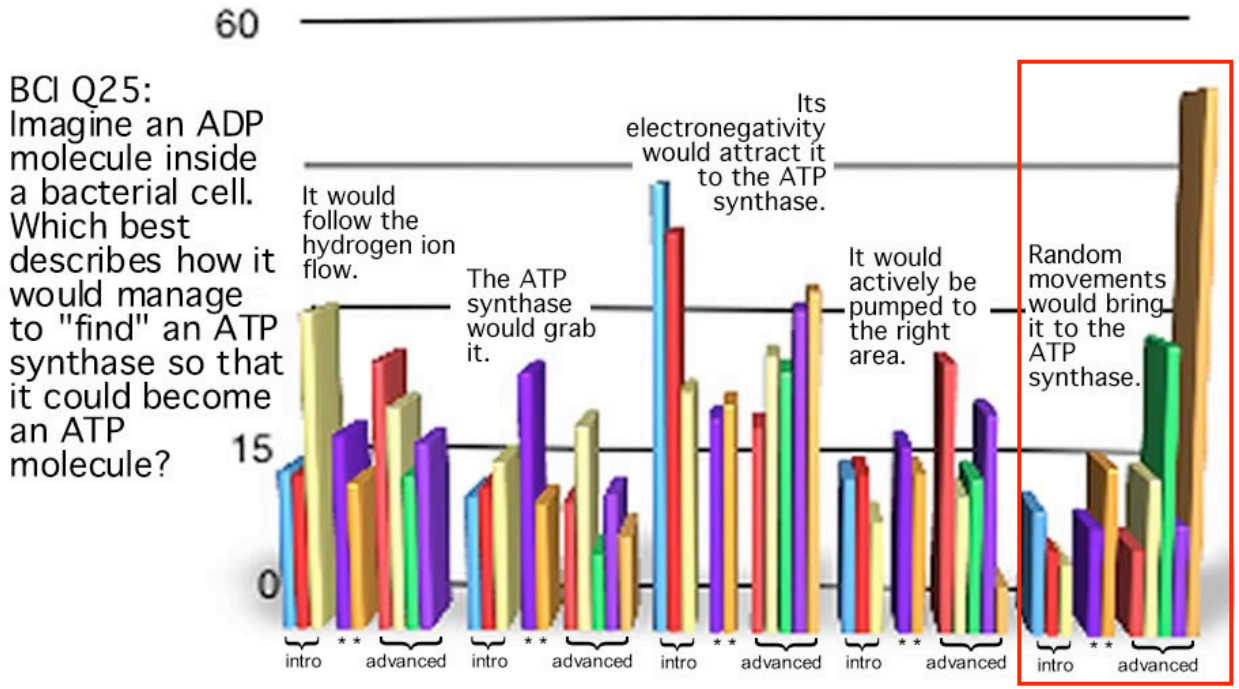


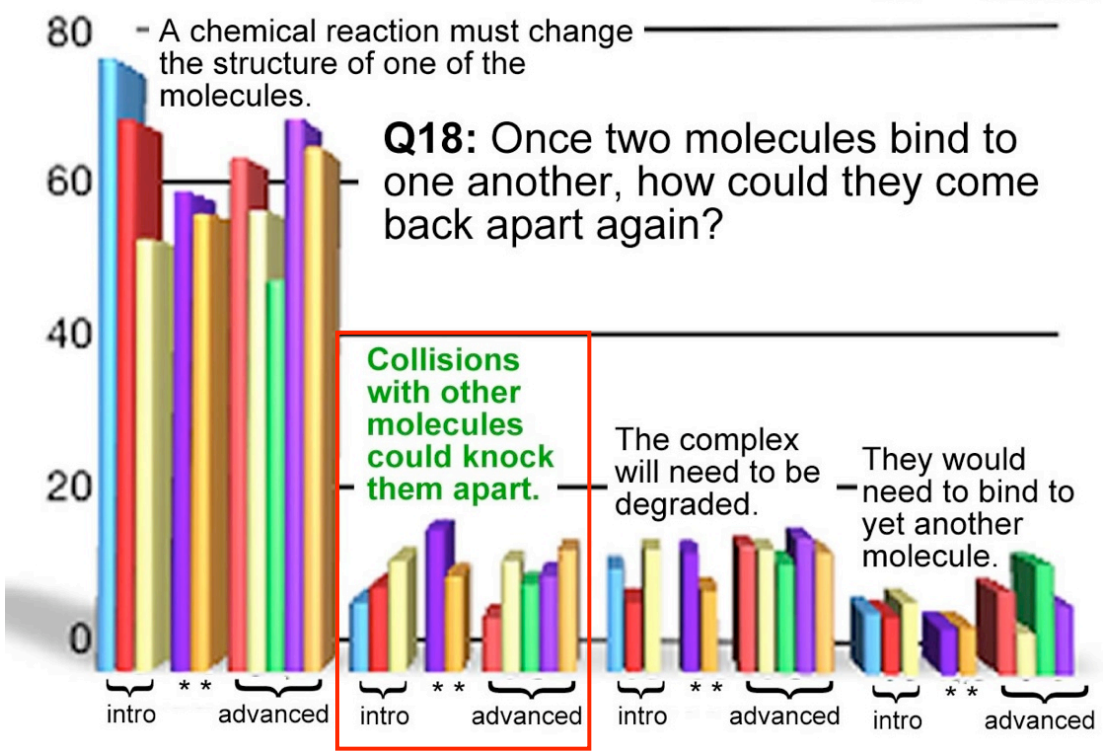
Biology's physiochemical foundations

Is there evidence that students have trouble with physiochemical ideas?



yes!

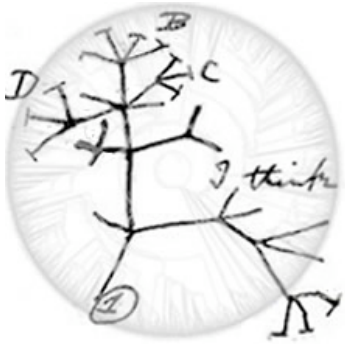




Students prefer "active agents" over random movements

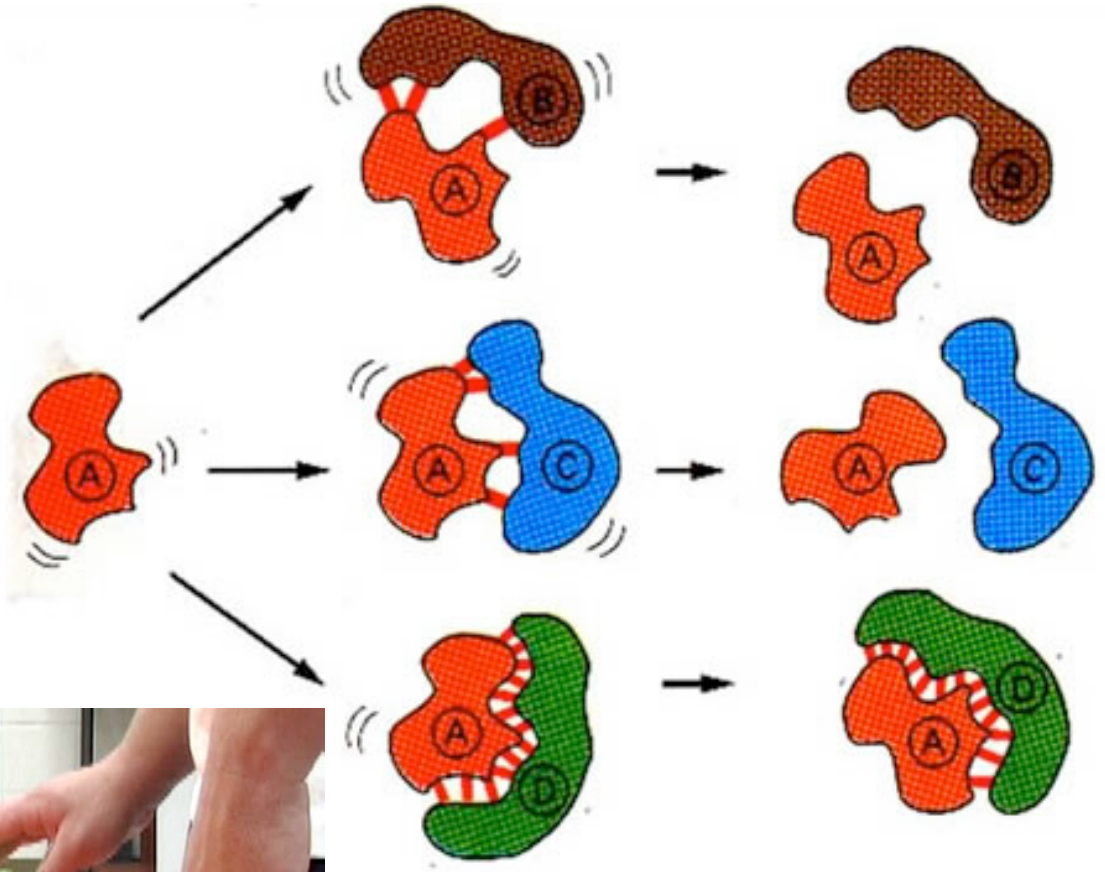
Garvin-Doxas & Klymkowsky. 2008. Understanding randomness and its impact on student learning: lessons learned from the Biology Concept Inventory (BCI). CBE Life Sci Educ **7**: 227-233.

Klymkowsky, Furtak, Garvin-Doxas, Cooper & Gonzales, Understanding molecular creativity and evolutionary change: conceptual barriers, curricular omissions and didaskalogenic obstacles. in preparation.



Didaskalogenic (instructor/instruction-induced) confusion

Molecules interact through lock and key/ jig-saw puzzle (geometric) mechanism



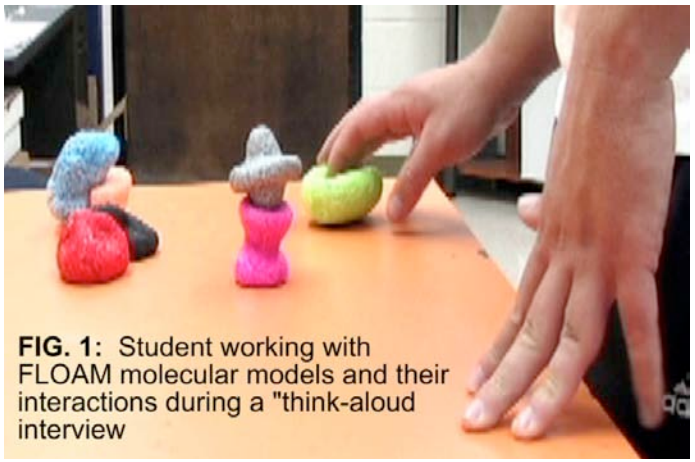
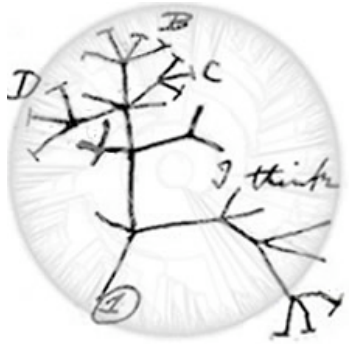
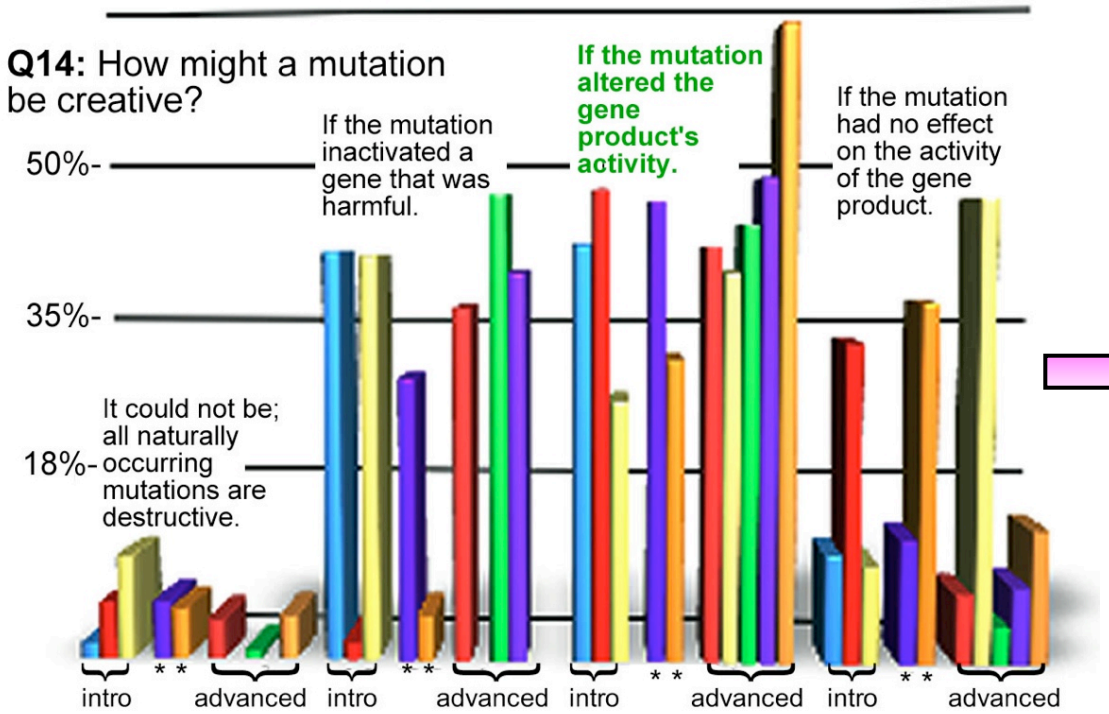


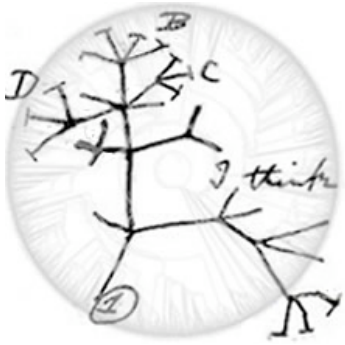
FIG. 1: Student working with FLOAM molecular models and their interactions during a "think-aloud interview



Deeply held assumption, either immune to, or unaddressed by subsequent instruction

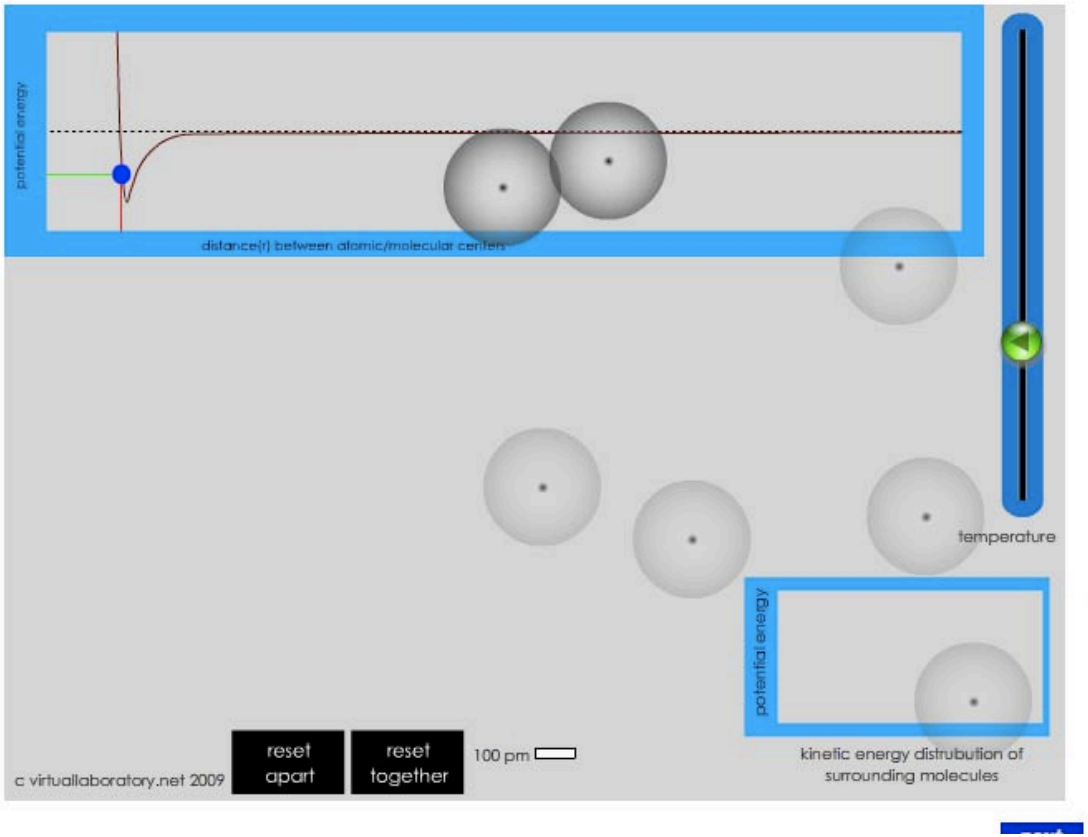


Altered keys do not work. Mutations are always destructive, never creative



Klymkowsky, Furtak, Garvin-Doxas, Cooper & Gonzales, Understanding molecular creativity and evolutionary change: conceptual barriers, curricular omissions and didaskalogenic obstacles. in preparation.

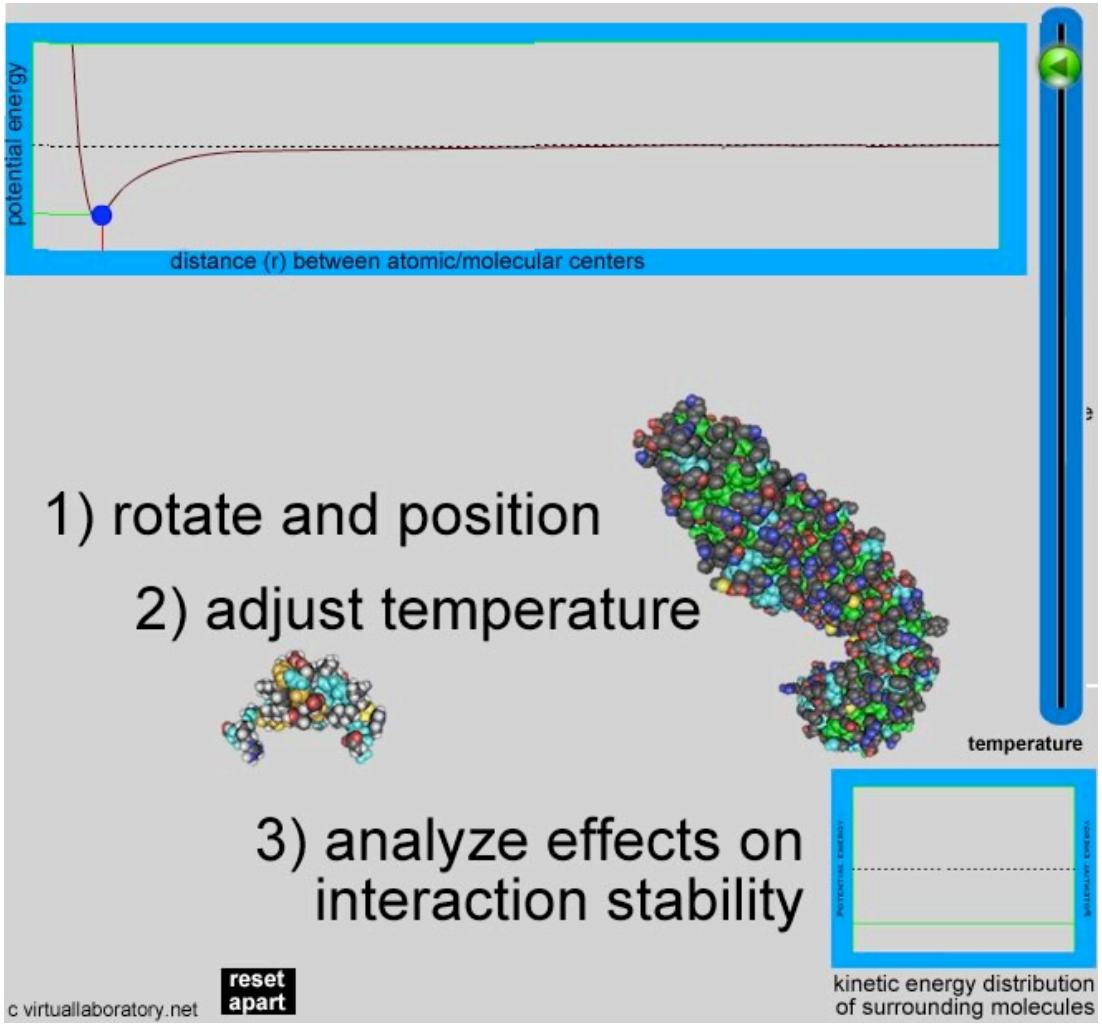
Students need to be introduced to how molecules interact, how bonds form, and how systems behave.



What does the student see, what questions can they address, can they apply key concepts to new situations?

Cooper & Klymkowsky (Lundy) Chemistry, life, the universe and everything. in preparation.

Students need test assumptions in new situations



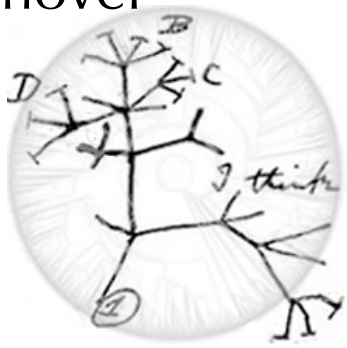
recognize:

1) the role of temperature as a determinant of stability

2) the reality of molecule promiscuity

3) the effects of mutations on interaction specificity, affinity, and activity

4) the need for gene duplication in the evolution of novel structures



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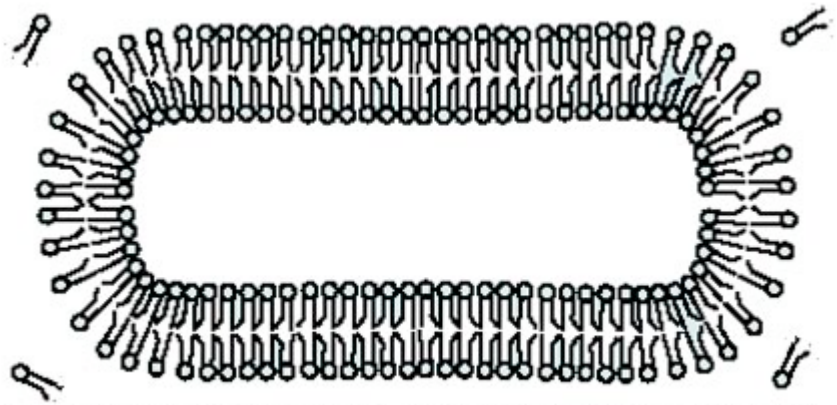
Students need to think thermodynamically - systemically

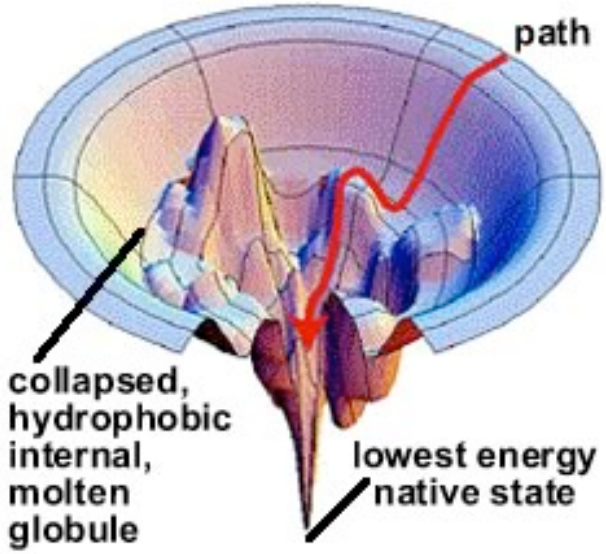


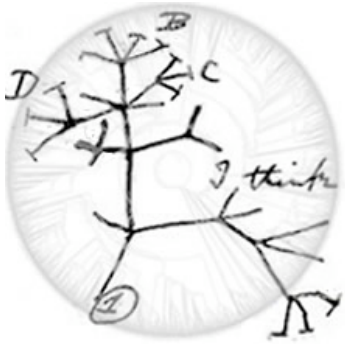
entropy of lipid in water - entropy of bilayer in water

recognize that it is the
differences between original and final state that matters (similar logic applies to energy release upon ATP hydrolysis)

increasing entropy drives the formation of ordered structures (origin of life)

primary determinant of protein folding





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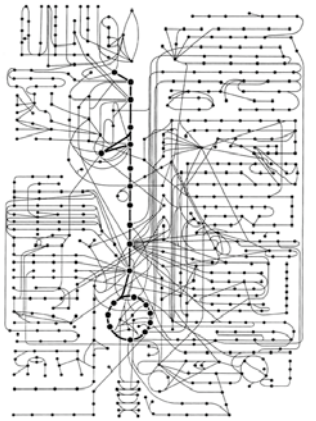
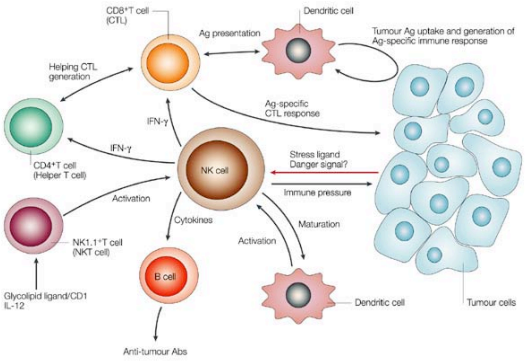
These are concepts with a physical foundation: are they taught in the physics courses most biology, chemistry, and K12 science teachers take?

Has the content of first year physics been critically analyzed vis-a-vis its relevance to non-physicists? Is it pedagogically justified?

Life is about (evolving) networks

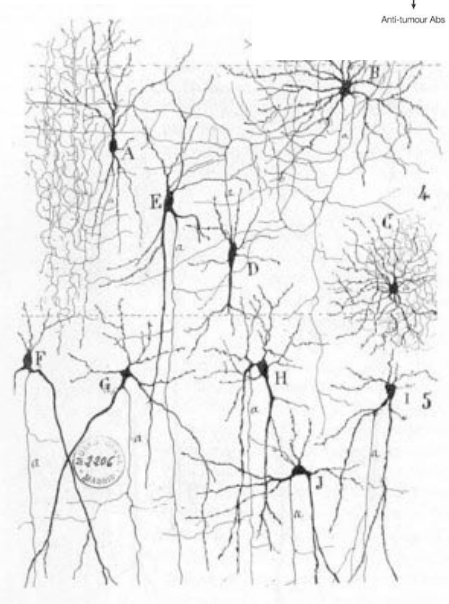


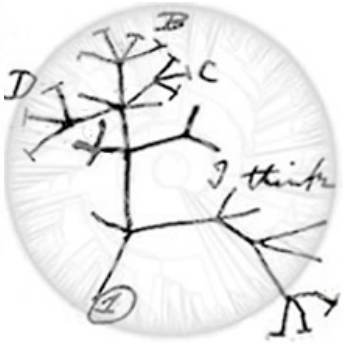
non-equilibrium, chemical reaction networks
gene regulatory networks



adaptive & homeostatic cellular networks
e.g. immune system / nervous system

social networks
ecological networks





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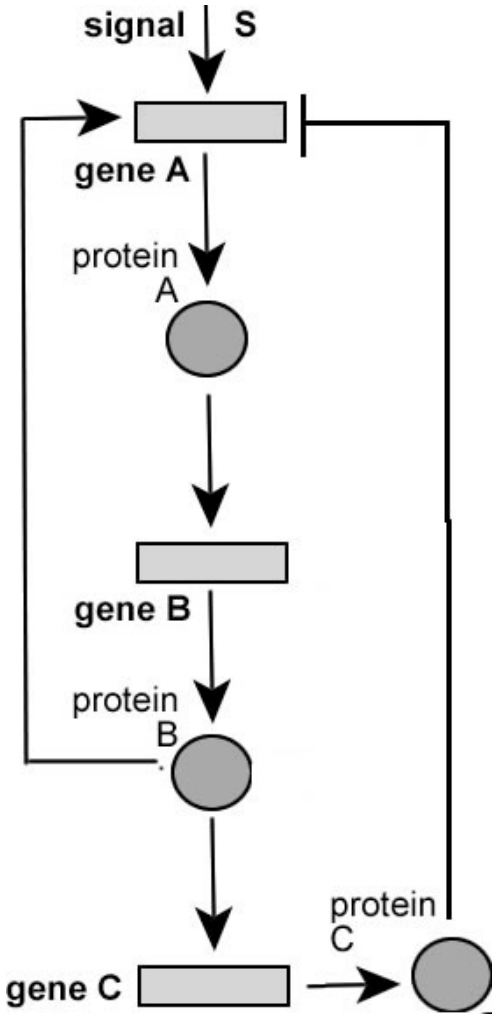
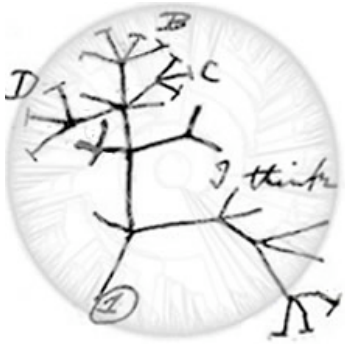
physics / mathematics could help with ...



analytic analysis of network behaviors

particularly in the context of stochastic* processes (such as RNA/polypeptide half-lives under conditions of small number of molecules

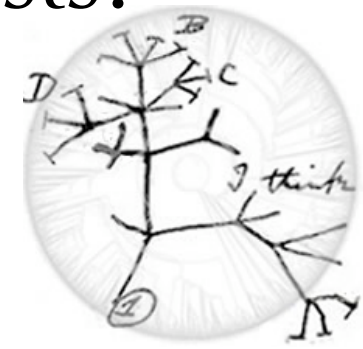
Q: Are physics/math responsible for the mathphobic predilection of (most) biologists?



*student confusion as to whether this is property of individual molecules versus populations of molecules

Understanding biology (evolution) depends on a robust understanding of physical principles - no vital forces or designers needed.

Question is, should the required physical concepts be taught by physicists, or are you comfortable with biologists teaching them? The same applies you, chemists!



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CU 🍎 **Teach** science/mathematic recruitment and certification program

NSF DUE: Building a basic biology concept inventory
NSF DUE: Chemistry and the logic of life
National Mathematics and Science Institute grant for CU🍎Teach