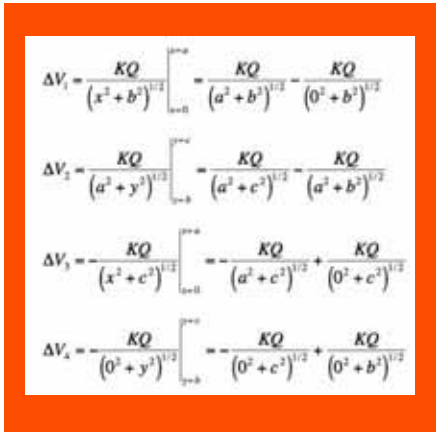
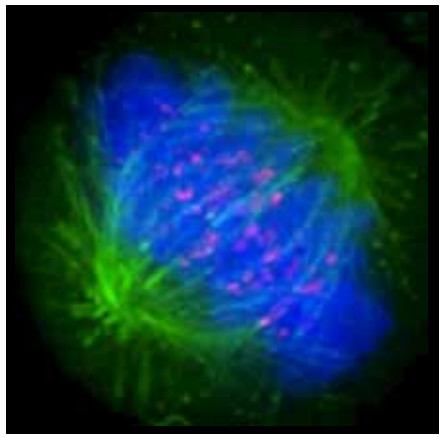


$$\Delta V_1 = \frac{KQ}{\left(x^2+b^2\right)^{1/2}}\Bigg|_{x=0}^{x=a} = \frac{KQ}{\left(a^2+b^2\right)^{1/2}} - \frac{KQ}{\left(0^2+b^2\right)^{1/2}}$$

$$\Delta V_2 = \frac{KQ}{\left(a^2+y^2\right)^{1/2}}\Bigg|_{y=0}^{y=c} = \frac{KQ}{\left(a^2+c^2\right)^{1/2}} - \frac{KQ}{\left(a^2+b^2\right)^{1/2}}$$

$$\Delta V_3 = -\frac{KQ}{\left(x^2+c^2\right)^{1/2}}\Bigg|_{x=0}^{x=a} = -\frac{KQ}{\left(a^2+c^2\right)^{1/2}} + \frac{KQ}{\left(0^2+c^2\right)^{1/2}}$$

$$\Delta V_4 = -\frac{KQ}{\left(0^2+y^2\right)^{1/2}}\Bigg|_{y=0}^{y=b} = -\frac{KQ}{\left(0^2+c^2\right)^{1/2}} + \frac{KQ}{\left(0^2+b^2\right)^{1/2}}$$



Transforming Introductory Physics for Life Scientists

Chandra Turpen
University of Maryland

HHMI

OUR RESEARCH TEAM

- Edward Redish
- Julia Svoboda
- Benjamin Dreyfus
- Benjamin Geller
- Todd Cooke
- Jessica Watkins
- Arnaldo Vaz

WHY SHOULD LIFE SCIENCE MAJORS TAKE PHYSICS?

Outline

- Improving conceptual understanding
- Improving epistemological sophistication
- Building coherence across disciplines (Current Efforts)

CONCEPTUAL UNDERSTANDING

EPISTEMOLOGY:
Nature of knowing and learning

Approaches to Learning Physics

UNFAVORABLE	FAVORABLE
Pieces of information learned separately	Coherent web of ideas to be tied together
Retaining formulas and problem-solving algorithms	Relating fundamental concepts to problem solving techniques
Learning as absorbing information	Learning as building one's own understanding

Hammer, *The Physics Teacher,* Dec. 1989

Typical Instruction is detrimental to expectations

- Enter with attitudes that agree with experts at ~ 50% to 65%.
- These attitudes deteriorate by 5-10% or more, whether or not the class has been reformed to produce improved conceptual learning.

Epistemology -- Gains

- *It is possible to achieve significant gains on an Expectations/Attitude survey without sacrificing conceptual gains.*
- *Elby (HS), Modeling (FIU), & other courses*

EPISTEMOLOGY:
Building coherence between physics and everyday intuitions

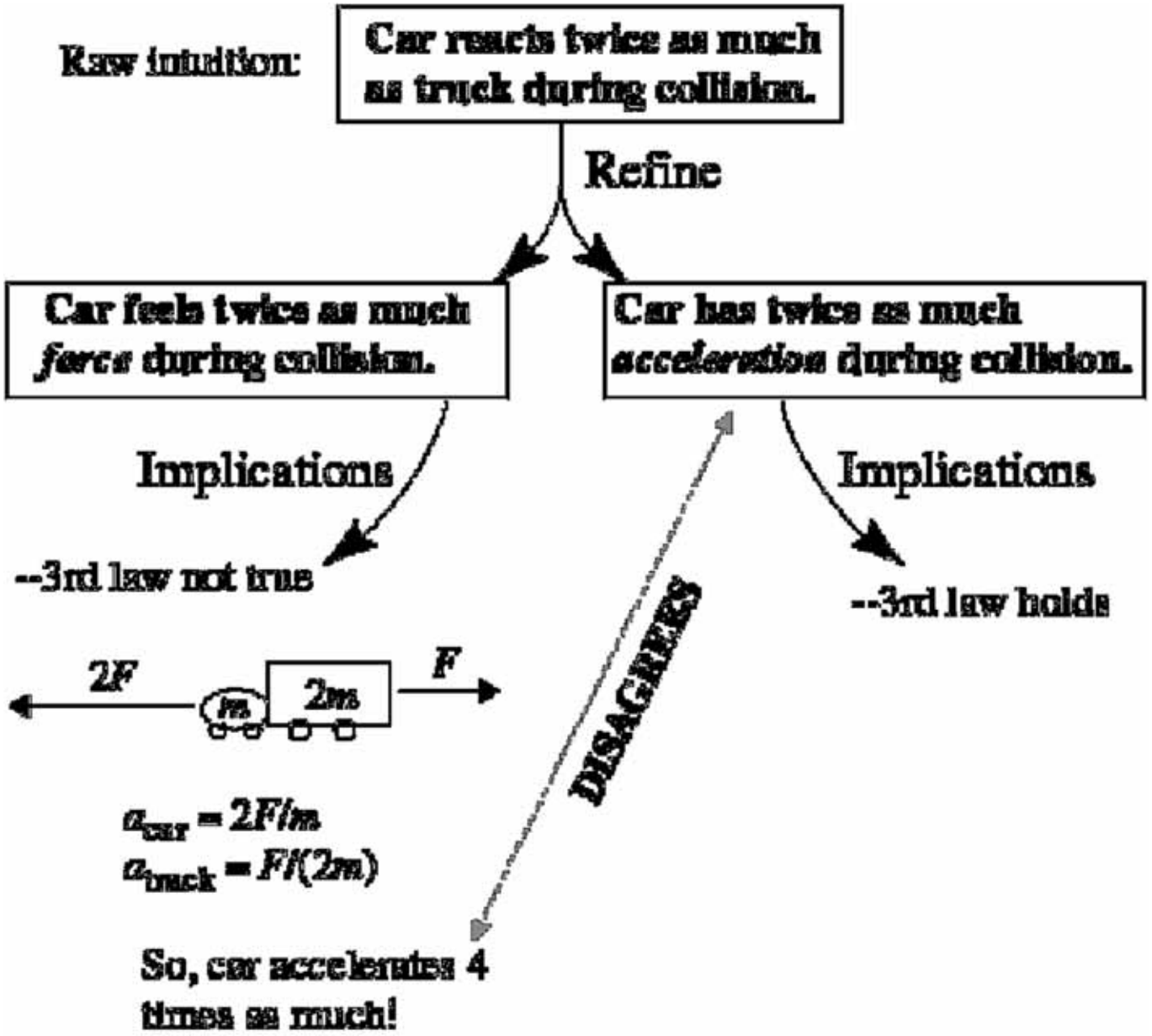
Tutorial

1. A truck rams into a parked car.

   (a) Intuitively, which is larger during the collision: the force exerted by the truck on the car, or the force exerted by the car on the truck?

   (b) Suppose the truck has mass 1000 kg and the car has mass 500 kg. During the collision, suppose the truck loses 5 m/s of speed. Keeping in mind that the car is half as heavy as the truck, how much speed does the car gain during the collision? Visualize the situation, and trust your instincts.

2. To simulate this scenario, make the “truck” (a cart with extra weight) crash into the “car” (a regular cart). The truck and car both have force sensors attached. Do whatever experiments you want, to see when Newton’s 3rd law applies.


Raw intuition:
Car reacts twice as much as truck during collision.
Refine
Car feels twice as much force during collision.
Car has twice as much acceleration during collision.
Implications
--3rd law not true
Implications
--3rd law holds
DISAGREES
2F
m
2m
F
$a_{car} = 2F/m$
$a_{truck} = F/(2m)$
So, car accelerates 4 times as much!

"Splitting"

- FCI given to an algebra-based Physics II class at start of second semester.
- Students (N~160) included 1/3 from traditional instruction, 2/3 from our reformed instruction with Elby pairs.
- Instructions:

"Please **circle** the answer
that makes the most intuitive sense to you.

Please draw a **square** around the answer
you think scientists would give."

A typical split

4. A large truck collides head-on with a small compact car. During the collision:

(A) the truck exerts a greater amount of force on the car than the car exerts on the truck

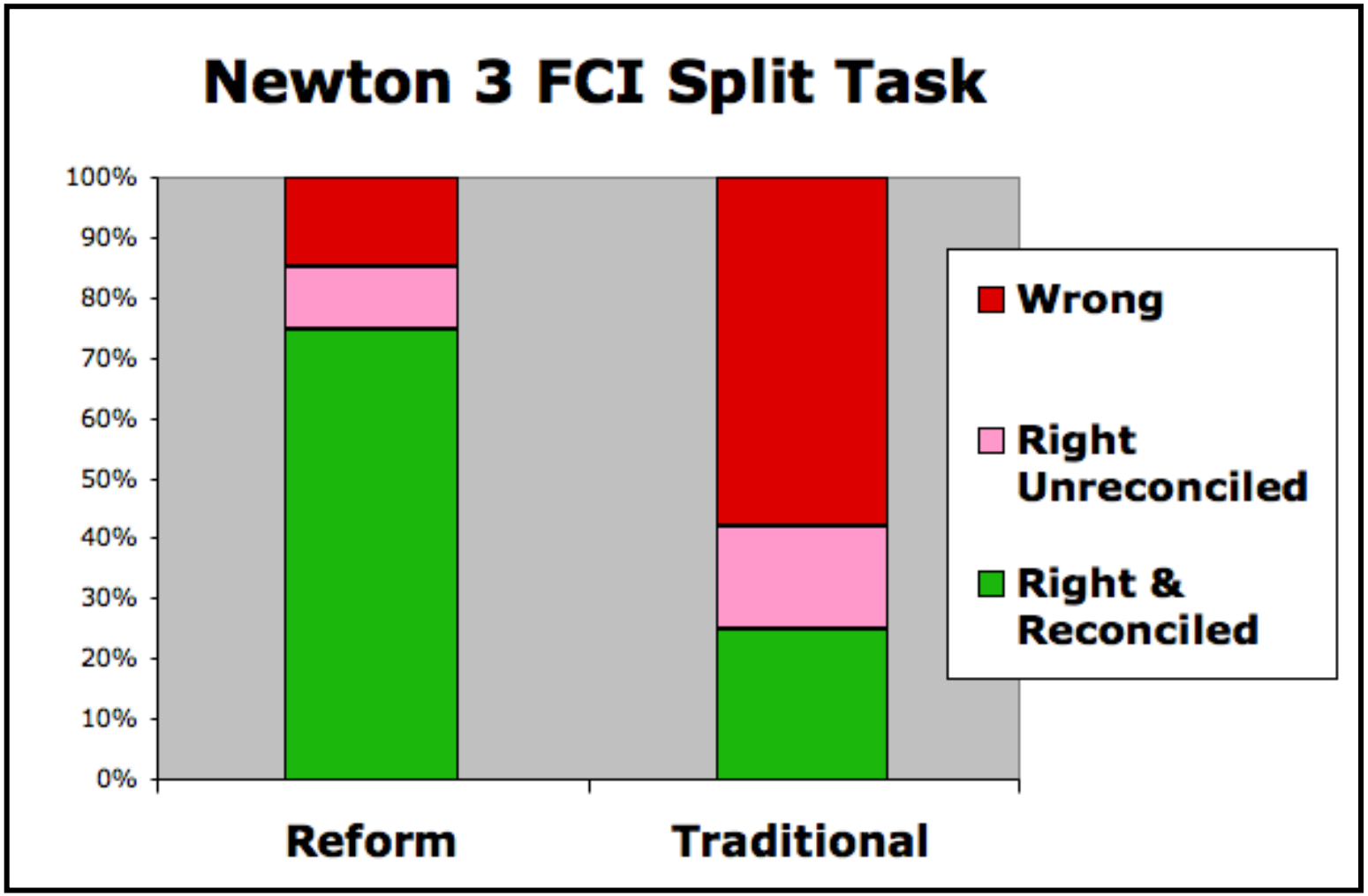
(B) the car exerts a greater amount of force on the truck than the truck exerts on the car

(C) neither exerts a force on the other, the car gets smashed simply because it gets in the way…

(D) the truck exerts a force on the car but the car does not exert a force on the truck

(E) the truck exerts the same amount of force on the car as the car exerts on the truck

Results



McCaskey and Elby

Coherence: Everyday Intuitions & Physics

- Students rarely spontaneously reconcile their everyday, or common sense knowledge with the material presented in their physics courses.
- Explicit scaffolding can help students refine their intuitions and build coherence.

EPISTEMOLOGY: Seeking coherence across disciplines

CASE #1 -- Ellen

Ellen's views on physics

- …as far as I understand physics the study of physics is, **not to say that it is removed from the world or totally irrelevant, but it is mathematical"**
- …it's about understanding the math behind something and the way something works **rather than the way it is applied naturally."**

CASE #1 -- Ellen

Concerns about relevance to "real world"

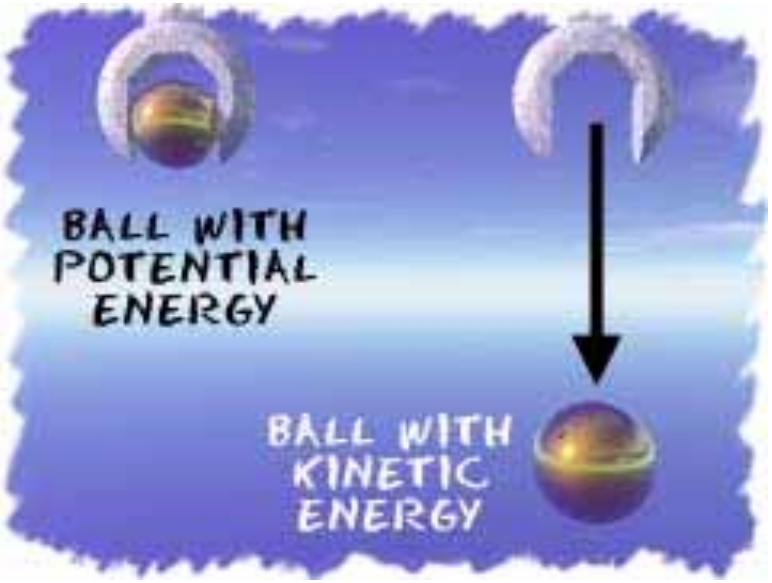
- "…six of these really similar, really non-realistic word problems where there is no friction"
- "have problems that have relevant applications to the principle that they've taught …in the real world."

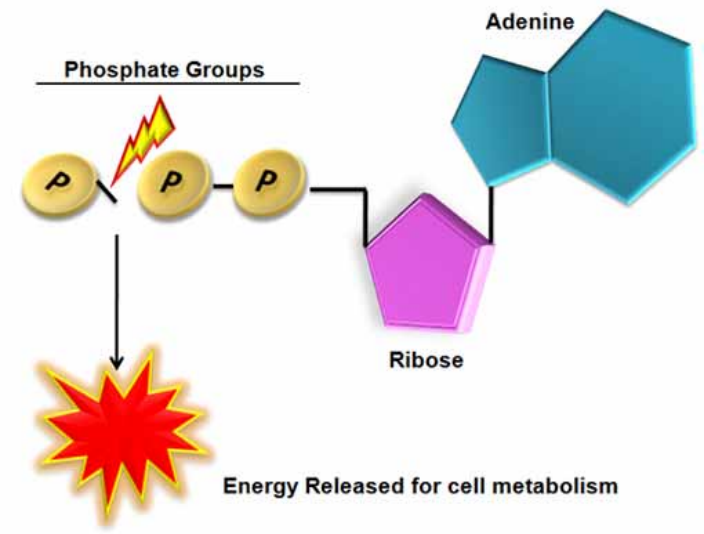
Case Study of "Dennis"

- Junior taking first-semester introductory physics
- Completed intro biology and chemistry sequences
- Completing pre-med requirements
- 2 interviews (focusing on energy)

Disconnect between Physics & Biology

- Physics class “talks a lot more about physical objects, stuff like that, which you don't really talk about in bio or chem. You don't really talk about macro stuff… Biology, it's more about interactions of molecules.”

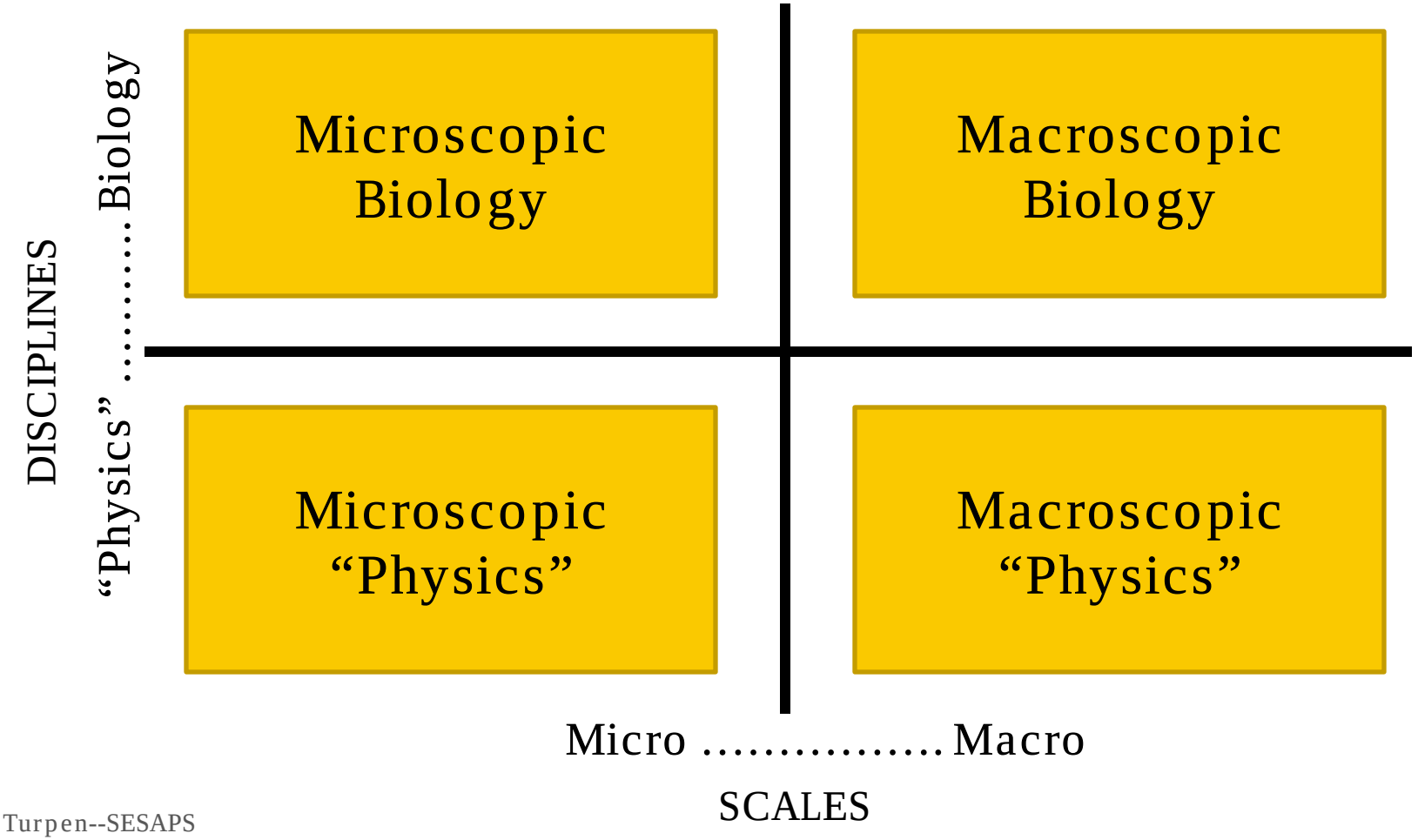




Disconnect between Physics & Biology

- “different units”
- “I'm saying even if there were a way to connect the two, which I … can't think of a way, I don't really think there would be a point in doing so.”

Barriers between domains



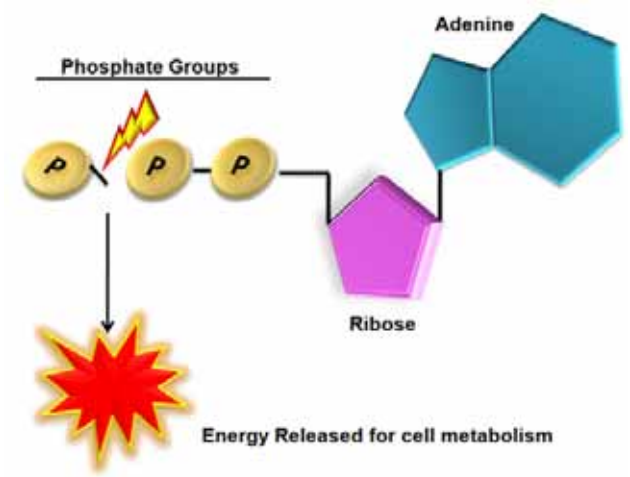
Macro Phys←→Micro Phys

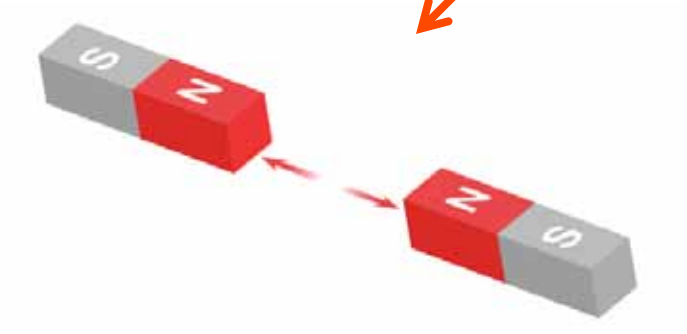
- "With a cannon, you ignite it, and you break the bonds that … have a whole lot of energy stored up … So I guess energy is kind of imparted from explosive material to the cannonball. From … I guess chemical energy, it gets converted into kinetic energy and that's a cannonball moving."

Micro Bio ←→ Micro Phys

- *“I guess it would be electrons, is where energy is stored, I guess would be the moral of the story. Yeah. 'Cause I mean if you look at redox reactions, that's, you know, the movement of electrons. Photosynthesis, you know, you plug in a photon and, you know, you essentially plug in an electron, it bumps up a state. And you know, solar power, it's the same thing, the sun's photons hit the solar power, you know, it bumps it up, it catches the current, it goes through a circuit. That's what creates the energy. So I guess electrons would kind of be the current. The currency.”*

Bridging


Adenine
Phosphate Groups
P
P
P
Ribose
Energy Released for cell metabolism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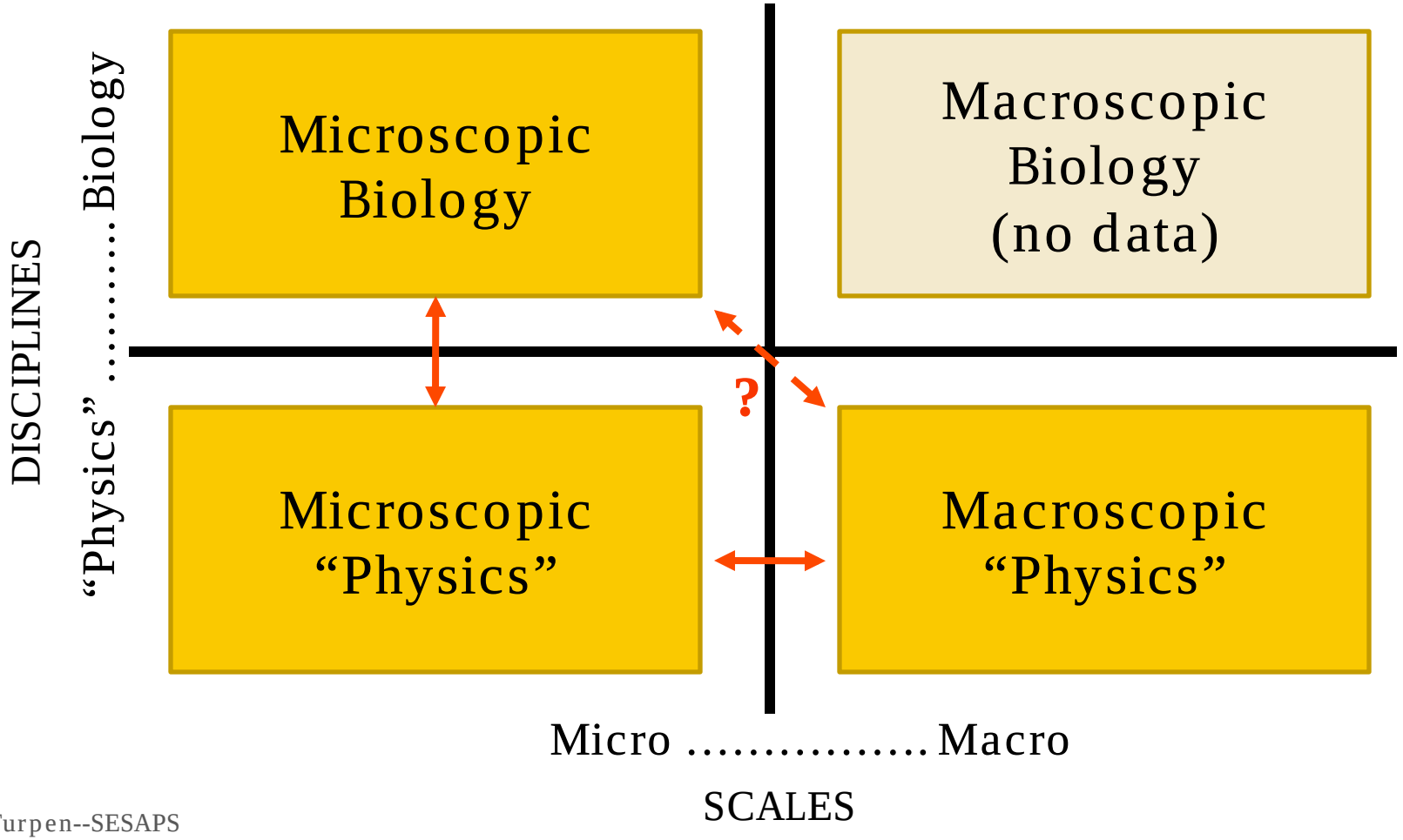
Microscopic Biology
Macroscopic Biology (no data)
Microscopic "Physics"
Macroscopic "Physics"
?
DISCIPLINES
"Physics" ..... Biology
Micro ..... Macro
SCALES

Lack of coherence…

- Many big ideas in science span disciplinary domains, i.e. energy, diffusion…
- Students often leave our courses without a coherent framework for thinking about these ideas.

Tendency of Physicists

- Intro physics often stresses reasoning from a few fundamental principles.
- Physicists often stress building a complete understanding of the simplest possible examples – and often don't go beyond them at the introductory level.
- Physicists often quantify their view of the physical world.
- Physicists think with equations.
- Introductory physics typically restricts itself to the macroscopic level and almost never considers chemical energy

Tendency of Biologists

- By its very choice of subject biology is complex.
- Most introductory biology is qualitative.
- Biology is fundamentally historical.
- Much of introductory biology is descriptive (and introduces a large vocabulary) though
- Biology – even at the introductory level – looks for mechanism and frequently considers micro to macro connections.
- Chemistry is much more important to intro bio than physics (or math).

Implications

- Epistemological differences between the disciplines have two broad implications.
  - Faculty in the different disciplines don't typically communicate well concerning service courses – if at all.
    - When they do communicate, they may not understand each other.
    - Service courses may not serve – or help students see relevance.
  - Students taking courses in multiple disciplines may not understand why they need them.
    - They may resist efforts to bring in knowledge across disciplines.
    - They may not spontaneous build connections across these domains.

Our decisions

- Present the class as a second year class with prerequisites
  - two semesters of bio (some intro so cellular, molecular, evolutionary, and ecological bio)
  - one semester of chemistry
  - one year of math (basic calculus and probability)
- Rely on a familiarity with biological systems and language to replace traditional macro examples by micro ones.
- Make modeling and the assumptions behind building models more explicit.

WHY SHOULD LIFE SCIENCE MAJORS TAKE PHYSICS?

Conclusion

- Creating a physics course for biologists that “looks right” (authentic) to both biologists and physicists is going to be a challenge, both in content and in epistemology.
- Students’ disciplinary expectations can play a major role, yielded unexpected resistances.
- But it’ll be fun…