Adding Value through Interdisciplinary Conversation

TRUSE 2012

NEXUS NATIONAL EXPERIMENT in Undergraduate Science Education

HHMI

Edward F. Redish
University of Maryland

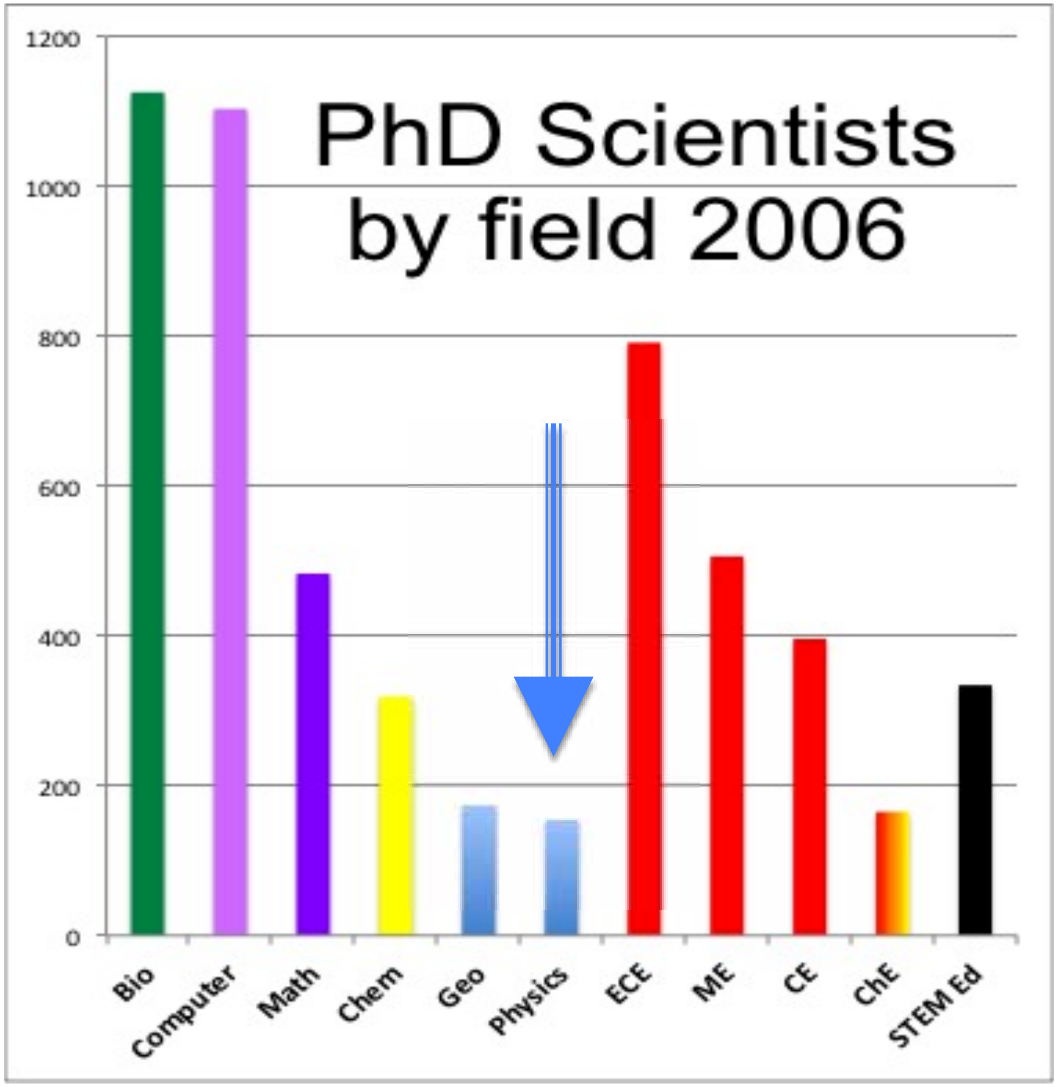
2

The background

Why physicists (and mathematicians and maybe all of us) ought to care about interdisciplinarity

The nature of physics departments

- Physics is a fairly small profession among the sciences.
- As a result, most of our teaching is in service courses.



When it comes to teaching non-physicists...Don’t mess with success!

- We know how to teach physics.
- Physics is physics is physics ... for everybody.
- We have a working model – and dozens of standard texts we can use with all kinds of resources.
  - This makes teaching non-majors fairly straightforward – even if time consuming due to the problems of administering large-classes.
- No thinking required!

Unfortunately...

- 1. Our clients have started to pay attention.
  - In 2000, ABET (the engineering accreditation organization) shifted its focus from course requirements to learning requirements.
  - In 2009, AAMC (the medical school organization) proposed to shift its focus from course requirements to learning requirements.

PER chimes in!

- 2. Over the past 20-30 years, research has increasingly shown the failure of large traditional physics courses to
  - build good concepts
  - improve student attitudes towards physics
  - help students learn to think scientifically
- Research-based instructional methods have begun to document learning – at least along some dimensions.

The challenge

Project NEXUS

The SFFP Report

- In 2009, AAMC working with HHMI published *Scientific Foundations for Future Physicians* – a call for rethinking pre-med education in the US to
  - bring in more and stronger coordinated science – biology, math, chemistry, and physics
  - focus on scientific skills and competencies

In the summer of 2010, HHMI put forth a challenge to four universities:

Create a proposal to develop four sets of prototype materials for biologists and pre-meds with a focus on scientific competency building and interdisciplinary links in

- *Chemistry (Purdue)*
- *Math (UMBC)*
- *Physics (UMCP)*
- *Capstone case study course (U of Miami)*

Project NEXUS

- The result is the **N**ational **Ex**periment in **U**ndergraduate **S**cience Education
  - A 4-year $1.8 M project of the Howard Hughes Medical Institute
- At UMCP we have opened an interdisciplinary conversation with the goal of creating a physics course explicitly designed to meet the needs of biologists and pre-health-care-professionals.

The NEXUS Development Team (UMCP)

- **Physicists**
  - Joe Redish
  - Wolfgang Losert
  - Chandra Turpen
  - Vashti Sawtelle
  - Ben Dreyfus
  - Ben Geller
  - Arnaldo Vaz (Br.)
- **Biologists**
  - Todd Cooke
  - Karen Carleton
  - Joelle Presson
  - Kaci Thompson
- **Education (Bio)**
  - Julia Svoboda
  - Gili Marbach-Ad
  - Kristi Hall-Burke

(Underlined are attending TRUSE)

Discussants: UMCP co-conspirators

- **Physicists**
  - Arthur LaPorta
  - Michael Fisher
  - Peter Shawhan
- **Biologists**
  - Jeff Jensen
  - Richard Payne
  - Marco Colombini
  - Patty Shields
- **Chemists**
  - Jason Kahn
  - Lee Friedman
- **Education**
  - Andy Elby (Phys)
  - Dan Levin (Bio)
  - Jen Richards (Chem)

Discussants: Off-campus collaborators

- Physicists
  - Catherine Crouch* (Swarthmore)
  - Royce Zia* (Virginia Tech)
  - Mark Reeves (George Washington)
  - Lilly Cui & Eric Anderson (UMBC)
  - Stephen Durbin (Purdue)
  - Dawn Meredith (U. New Hampshire)
- Biologists
  - Mike Klymkowski* (U. Colorado)
- Chemists
  - Chris Bauer* (U. New Hampshire)
  - Melanie Cooper* (Clemson)

NSF TUES project

(Underlined are attending TRUSE)

After much negotiation: PHYS 131-132

- A separate course specifically designed to meet the needs of biology majors and pre-meds.
- Intended as a second year class. Prerequisites:
  - 2 terms of biology
    - Intro to cellular, molecular, evolution, ecology
  - 1 term of general chemistry
  - 2 terms of math for bio majors
    - including basic calculus and probability
- We will consider ourselves successful if upper division bio classes require us as a prerequisite.
- A first draft of this class was delivered in '11-'12.

17

Barriers to interdisciplinarity

Our initial negotiations immediately ran into a brick wall. Biologists and physicists had very different views of what to do.

Starting in a hard place

- Biologists saw most of the traditional introductory physics class as useless and irrelevant to biology – and our standard approach: “we can just apply physics in biological contexts” as trivial and uninteresting.
- Physicists saw a coherent structure with no room for change.

A comment from a physics colleague

I would be inclined also to approach it from the "other end": i.e., I would construct a list which has in it the absolute irreducible physics concepts and laws that have to be in a physics curriculum. This "entitlement" list will already take up a majority of the available space.

With a realistic assessment of how much space is available, it may become clearer what type of bio-related material one can even entertain to include.

In two semesters it is impossible to cover every topic in physics. The purpose of this question is to determine your priorities of the topics in the course. Below are the chapter headings from a typical textbook at this level. Please place the **integer** number of weeks for each chapter that, **in your judgment**, allows students to understand the material at the level you desire. Each week consists of 3 lectures, 1 discussion section, and a 2-hour laboratory. The total number of weeks should equal 26 to account for a course introduction at the beginning of the semester and a review at the end. **Please do not use fractions of a week.**

_____	Units, dimensions and vectors
_____	Linear motion
_____	Two dimensional motion
_____	Forces and Newton's Laws
_____	Applications of Newton's laws
_____	Kinetic energy and work
_____	Potential energy and conservation of energy
_____	Momentum and collisions
_____	Rotations and torque
_____	Angular momentum
_____	Statics
_____	Gravitation
_____	Oscillatory motion
_____	Mechanical waves
_____	Superposition and interference of waves
_____	Fluid mechanics
_____	Temperature and ideal gas
_____	Heat flow and the first law of thermodynamics
_____	Molecules and gases (e.g. probability distributions of velocity, equipa
_____	Entropy and the second law of thermodynamics
_____	Properties of solids (e.g. stress, strain, thermal expansion)
_____	Electric charge and force
_____	Electric field
_____	Gauss' law
_____	Electric potential
_____	Capacitors and dielectrics
_____	Currents in materials (e.g. resistance, insulator, semiconductors)
_____	Currents and DC circuits
_____	Magnetic forces and fields
_____	Currents and magnetic fields (e.g. Ampere's law, Biot-Savart law)
_____	Faraday's law
_____	Magnetism and matter (e.g. ferromagnetism, diamagnetism)
_____	Magnetic Inductance
_____	AC circuits
_____	Maxwell's equations and electromagnetic waves
_____	Geometrical optics (e.g. reflection and refraction)
_____	Mirrors and lenses
_____	Interference
_____	Diffraction
_____	Quantum physics
_____	Atomic physics
_____	Nuclear physics and radioactive decay
_____	Particle physics
_____	Relativity
_____	Other. Please specify.
26	**Total number of weeks**

Content is just a part of the story!

- There is a “hidden curriculum” – what we want and expect our students to learn about how to think and how to do science while they are learning the facts and methods taught in our classes.

From *SFFP* (AAMC-HHMI)

Competency E1 *Apply quantitative reasoning and appropriate mathematics to describe or explain phenomena in the natural world.*

Competency E2 *Demonstrate understanding of the process of scientific inquiry, and explain how scientific knowledge is discovered and validated.*

Competency E3 *Demonstrate knowledge of basic physical principles and their applications to the understanding of living systems.*

(Four more explicitly relevant for biology and chemistry)

- To figure out how to pull all this apart and make sense of what is going on, we need to understand something about how people build coherent knowledge.
- We are not just talking about teaching students some facts – or even procedures.
- We are trying "acculturate" our students – bring them into a scientific community of practice.

24

A framework for talking about our differences

Thinking about thinking:
some basic psychological principles

Experiment 1:
How good is your memory?

Thread	Thimble	Bed	Rest
Pin	Haystack	Awake	Tired
Eye	Knitting	Dream	Snooze
Sewing	Cloth	Blanket	Doze
Sharp	Injection	Slumber	Snore
Point	Syringe	Nap	Yawn

Roediger & McDermott J. Exp. Psych: Learning, Memory, & Cognition. 21 (1995) 803-814.

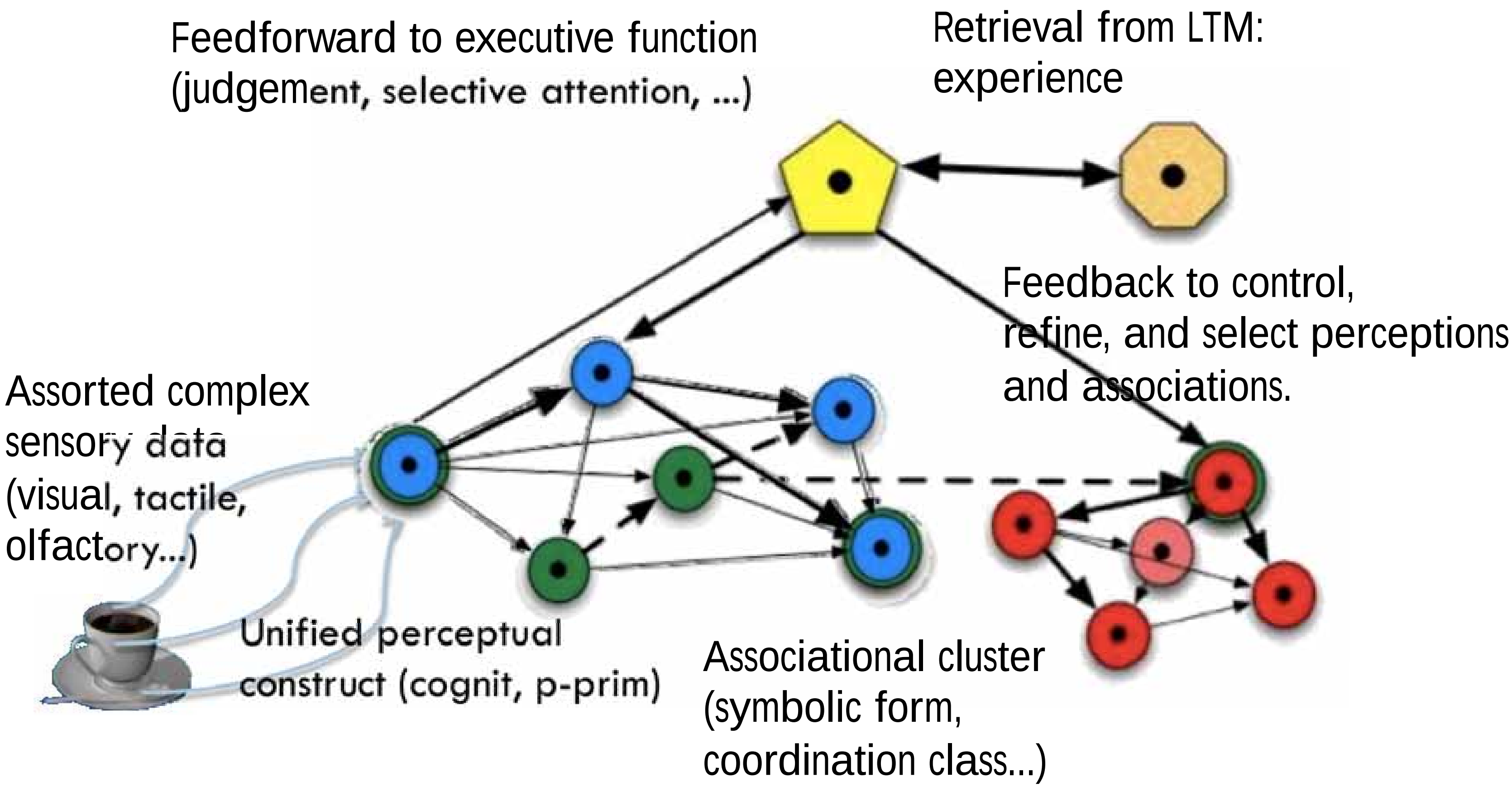
Experiment 2: How good is your concentration?

Simons & Chabris, Perception. 28:9 (1999) 1059-1074

Implications

- Memory is reconstructive and dynamic
- What students call on in class is based on their previous experience with school (and science classes).
- Inappropriate <u>student</u> expectations can lead them to "miss the gorilla in the classroom" and miss the point of an activity.
- Inappropriate <u>faculty</u> expectations can lead to disappointment and tension with students.

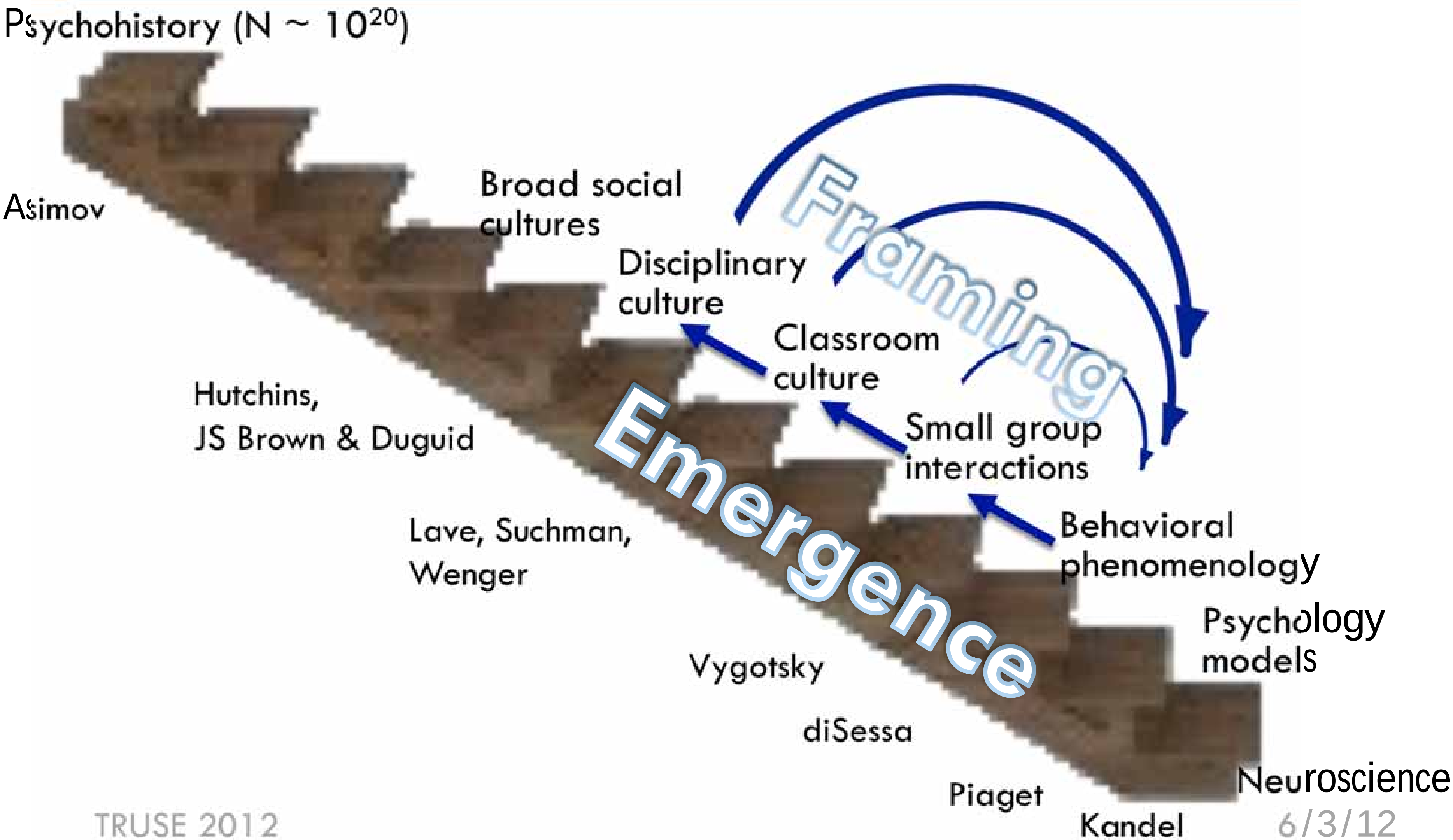
A structure for thinking about thinking



Key concepts for discussing interdisciplinarity

- Framing –
  - The process of “choosing” a set of data in your environment to selectively pay attention to – equivalent to deciding that everything else can be safely ignored.
- Epistemology –
  - Knowledge about knowledge:
    What is the nature of the knowledge I am going to learn in this class and what is it that I need to do to learn it?
- Ontology –
  - What kinds of things are we talking about?

The cognitive/socio-cultural grainsize staircase



Framing

- The behavior of individuals in a context is affected by their *perception* of the social context in which they find themselves.
- That perception acts as a control structure that governs which of their wide range of behavioral responses they activate/use in a given situation.

The culture of disciplines

- From each level of their experience with a discipline – small group, STEM classes, broader school experiences – students bring control structures that tell them what to pay attention to in the context of activities in a science class.
- Their framing of the activity affects how they interpret the task and what they do.

Negotiating interdisciplinarity

It doesn't only matter what *we* think;
how our students frame their science classes
is critical to what they get out of them.

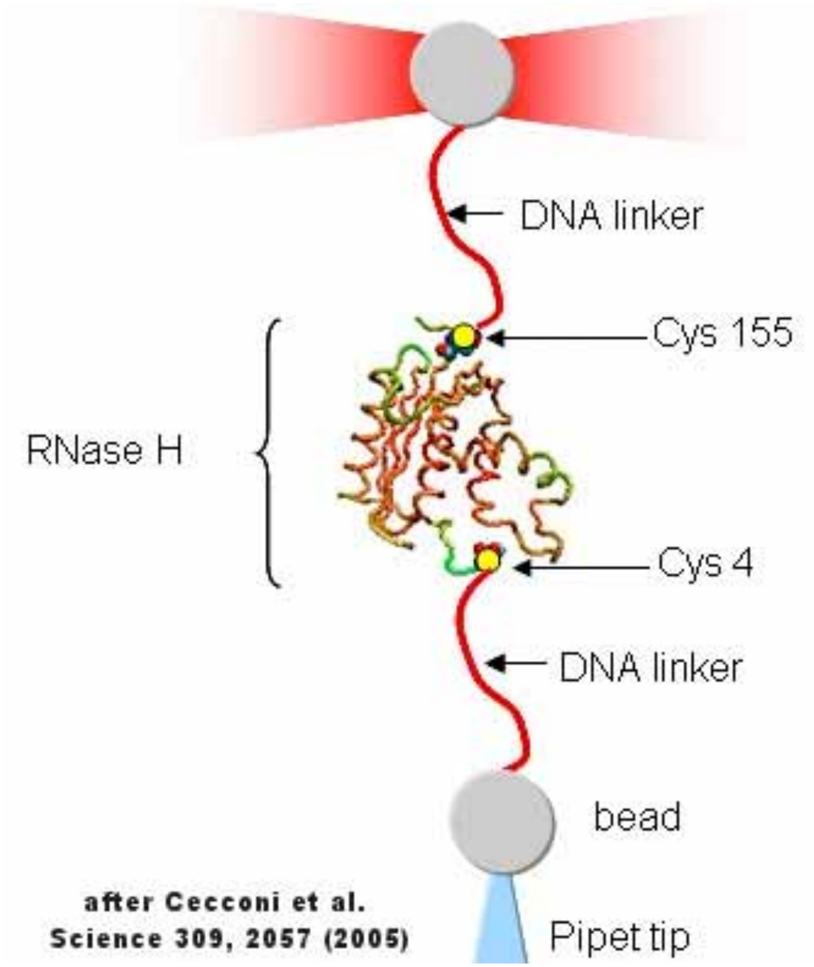
Student attitudes towards interdisciplinarity: some data

- We have interviewed students about their attitudes towards mixing the sciences in two classes:
  - Bio 3 – Organismal Biology
    A required bio class that explicitly uses a lot of physics and chemistry.
  - Phys 131-132 – Physics for Biologists
    The first implementation of the NEXUS physics course that brings in a lot of bio and chem.

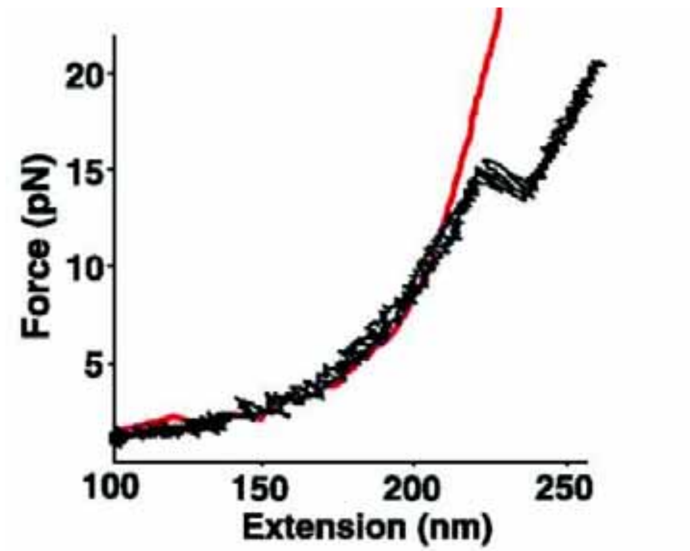
Biology students bring expectations to their physics and biology classes.

Ashlyn prefers to stay in silos

An example in Phys 131 (Recitation activity)



Estimate the work done in the particular unfolding shown.



It didn't work the way we wanted

Anya knows how complex biology "really" is so resists seeing how a simplified model might provide some useful info.

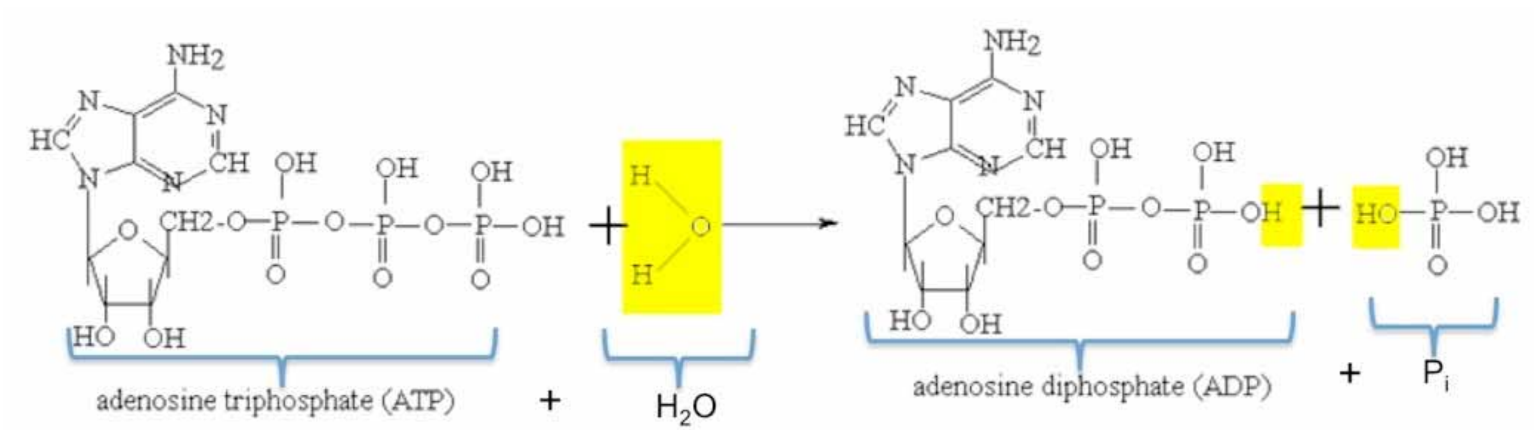
...protein folding is so complicated that you know you haven't even gotten up to what proteins are made of but just the protein itself is really complicated ... it was trying to apply a very simple basic physics thing to a whole protein, like even a subset of a protein ... and that was just not flying with us, because we knew it was really complicated and it was the sum of all these like interactions, and there's multiple kinds and it just isn't something that seems simple like that and it just didn't work because it's simplifying something that's really complicated too much.

But this *is* the way they do it!

- Anya had strong disciplinary epistemological framings:
  - Biology is really complicated and you have to work your way up in the structure to get the whole thing.
  - Physics oversimplifies by trying to model only a particular substructure of the protein.
- She showed this framing in other examples as well.

An example in Physics 132: A Chemistry “misconception”

- A critical biochemical process is the hydrolyization of ATP. This is the primary reaction that is used to deliver energy in biological systems.
- In chemistry it is identified as a “misconception” that students assume “energy is stored in the ATP bond” whereas really the energy comes from going from the weaker ATP bond to the stronger water-P bond.



A question from the chem ed literature

An O-P bond in ATP is referred to as a "high energy phosphate bond" because:

A. The bond is a particularly stable bond.

B. The bond is a relatively weak bond.

C. Breaking the bond releases a significant quantity of energy.

D. A relatively small quantity of energy is required to break the bond

W. C. Galley, J. Chem. Ed., 81:4 (2004) 523-525.

	Phys 132	Galley
A	32%	41%
B	47%	31%
C	79%	87%
D	26%	7%

Perhaps it's not always a misconception – sometimes it may be a framing issue.

About 1/3 of the students said both "the bond is weak" and "the bond releases a lot of energy". Gregor sees both as right.

I put that when the bond's broken that's energy released. Even though I know, if I really think about it, that obviously that's not an energy-releasing mechanism ... you always need to put energy in, even if it's like a really small amount of energy to break a bond. Yeah, but like. I guess that's the difference between like how a biologist is trained to think, in like a larger context and how physicists just focus on sort of one little thing. ... I answered that it releases energy, but it releases energy because when an interaction with other molecules, like water, primarily, and then it creates like an inorganic phosphate molecule that...is much more stable than the original ATP molecule.... I was thinking that larger context of this reaction releases energy.

Disciplinary cultures

- Although each scientific discipline has many practitioners with different approaches, our discussions with faculty and students leads us to consider some broad common themes.

Physics

- Intro physics often stresses <u>reasoning from a few fundamental (mathematically formulated) principles</u>.
- Physicists often stress building a complete understanding of the <u>simplest possible (often abstract) examples</u> – and often don't go beyond them at the introductory level.
- Physicists <u>quantify</u> their view of the physical world, <u>model with math,</u> and <u>think with equations</u>.
- Introductory physics typically restricts itself to the <u>macroscopic level</u> and almost never considers chemical bonds.

How physics looks to non-physicists

Biology

- By its very choice of subject biology is <u>irreducibly complex</u>. (Oversimplify and you die.)
- Most introductory biology is <u>qualitative</u>.
- Biology contains a fundamental <u>historical</u> component.
- Much of introductory biology is <u>descriptive</u> (and introduces a large vocabulary) though
- Biology – even at the introductory level – looks for <u>mechanism</u> and often considers micro-macro connections.
- Chemistry is much more important to intro bio than physics (or math).

Chemistry

- Chemistry is about how atoms interact to form molecules.
- Chemistry <u>develops high-level principles and heuristics</u> to help you think about how complex reactions take place.
- Chemistry frequently <u>crosses scales</u>, connecting the microscopic with the macroscopic.
- Chemistry often <u>assumes a macroscopic environment</u> – a liquid, gas, or crystal.
- Chemistry often <u>simplifies</u> -- selecting the dominant reactions to consider, idealizing situations and processes in order to allow an understanding of the most salient features.

Mathematics

- Mathematics is about logical structures and abstract relationships. It's not "about" anything physical.
- Math focuses on logical completeness – "proof" – and the tightness of arguments that can be constructed within a restricted set of axioms and principles.
- Most mathematicians I have spoken to want to deliver an "honorable" course – to all students, not just majors; one that correctly represents the mathematical structure of abstraction, reasoning, and proof.

Content: What's privileged?

- Physicists see their subject as built up carefully from observation and the establishment of general principle.
- To them, much that is done is essential for what will come later.
- Physicists see inclined planes as essential (to learn to manipulate vectors in the simplest possible situation) and what happens in fluids as much too complex to be done in an intro class (from first principles).

Content: What's authentic?

- Biologists see much (most?) of what we do in traditional intro physics as peripheral (at best) or irrelevant (at worst) to what biology students need to know.
- Biologists see most of the "biology examples" put into an IPLS class as trivial, uninteresting, and "not real biology".
- We want to seek content and examples that will be seen by biologists (and by biology students) as ***authentic*** – it helps make sense of something that has real importance in biology.

The Inclined Plane/Projectiles Debate

- *Pro:* Our physicists saw these topics as crucial for learning how to use vectors, a general and powerful tool.
- *Con:* Our biologists saw the inclined plane and projectiles as typical physics hyper-simplification with little or no value.
- *The resolution:* We replaced these topics with examples from biological motion and moved electric forces to the beginning to provide serious vector examples.

The Force / Energy Debate

- *Pro*: Our biologists saw the emphasis on forces as superfluous and requested we do everything in terms of energy.
- *Con:* Our physicists considered forces as "privileged" – essential to establishing the fundamental concepts of motion.
- *The resolution:* We reframed the treatment of forces as "The Newtonian Framework" – analogous to "The Evolutionary Framework" in biology; something that sets the language and ontology – what you look for. This also clarified what was model and what was framework.

Content decisions

- Include atomic and molecular examples from the first (since chem is a prereq.)
- Enhance the treatment of energy, reduce the discussions of force and momentum.
- Expand the treatment of thermodynamics and diffusion dramatically.
- Eliminate (ouch!) rotations, angular momentum, and magnetism.
- Include (as often as possible) authentic biological and chemical contexts and examples.

New approaches

- Be very explicit about modeling
  - Why simple examples are done.
  - What is being ignored – and why.
- Be very explicit about epistemology
  - The danger of recall and “one-step thinking”.
  - Building a safety net – a web of coherence
  - Checking / metacognition
- Use examples and problems from modern biology and medicine research.

Conclusion

We're started on a long path

- The task of creating an effective physics course for biology students turned out to be much harder and more interesting than we expected.
- We have learned much even at this early stage about disciplinary cultures – both among faculty and students.
- There is still much to be done! Stay tuned!

For more detail see our posters

- Ben Geller
  - **Research on Students' Reasoning about Interdisciplinarity**
- Julia Svoboda
  - **Analyzing the interdisciplinary nature of tasks in a physics course for life science majors**
- Chandra Turpen
  - **Conceptualizing "disciplinary" in research and design of interdisciplinary learning contexts**