

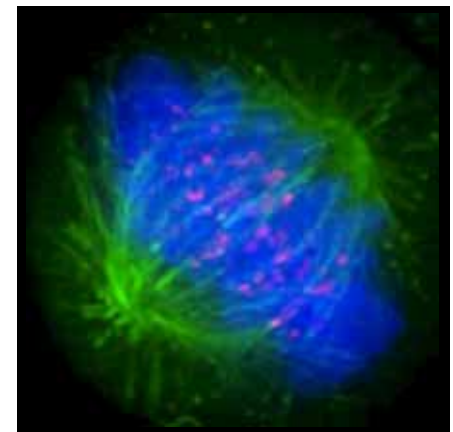


$$\Delta V_1 = \frac{KQ}{(x^2 + b^2)^{3/2}} \Big|_{-\infty}^{+\infty} = \frac{KQ}{(a^2 + b^2)^{3/2}} - \frac{KQ}{(0^2 + b^2)^{3/2}}$$

$$\Delta V_2 = \frac{KQ}{(a^2 + y^2)^{3/2}} \Big|_{-\infty}^{+\infty} = \frac{KQ}{(a^2 + c^2)^{3/2}} - \frac{KQ}{(a^2 + b^2)^{3/2}}$$

$$\Delta V_3 = \frac{KQ}{(x^2 + c^2)^{3/2}} \Big|_{-\infty}^{+\infty} = -\frac{KQ}{(a^2 + c^2)^{3/2}} + \frac{KQ}{(0^2 + c^2)^{3/2}}$$

$$\Delta V_4 = -\frac{KQ}{(0^2 + y^2)^{3/2}} \Big|_{-\infty}^{+\infty} = -\frac{KQ}{(0^2 + c^2)^{3/2}} + \frac{KQ}{(0^2 + b^2)^{3/2}}$$



Rethinking Physics for Biologists: Considering Value Added

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HHMI

+ To help me tune this talk

- How do you identify yourself professionally?
 1. As a physicist
 2. As a biologist
 3. As a biophysicist
 4. As a chemist
 5. As something else.



+ What is the field of your undergraduate training?

1. Physics
2. Biology
3. Chemistry
4. Engineering
5. Mathematics



+ Some speculations –
opening a conversation
on interdisciplinary education

+ Biology is changing

- Over the past decade, biologists have begun to call for **a major reform of undergraduate biology education.**
- Part of this reform is to include **more math, chemistry, and physics in bio classes.**
- Part is a call for **making math, chemistry, and physics classes more relevant to bio students.**

+ Some comments from the leadership.

- Biology is rapidly becoming a science that demands more intense mathematical and physical analysis than biologists have been accustomed to, and such analysis will be required to understand the workings of cells.

(H. Varmus, APS News, 1999)

- The departmental structures at most universities seem to have thus far prevented any major rethinking of what preparation in mathematics, what preparation in physics, and what preparation in chemistry is most appropriate for either research biologists or the medical doctors who will be working 10 or 20 years from now. The result is a major mismatch between what today's students who are interested in biology should be learning and the actual course offerings that are available to them.

(B. Alberts, Cell, 1998)

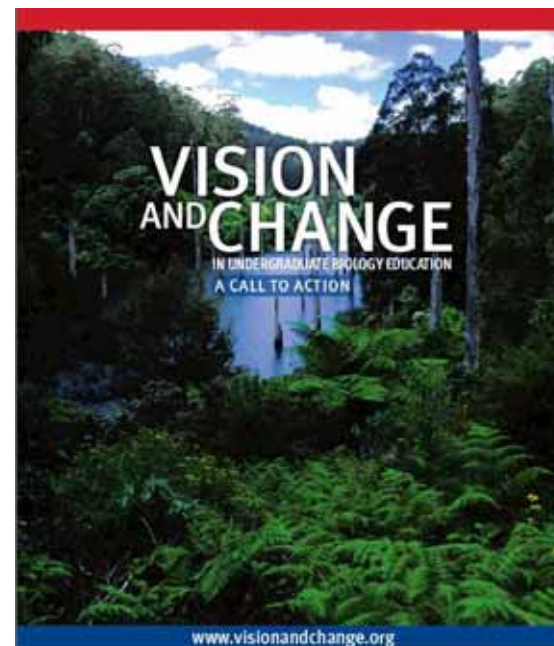
+ Calls for Bio Education Reform



NAS 2003



HHMI-AAMC 2008



AAAS 2009

+ Comments from the reports

- Life sciences majors must acquire a much stronger foundation in the physical sciences (chemistry and physics) and mathematics than they now get. Connections between biology and the other scientific disciplines need to be developed and reinforced so that interdisciplinary thinking and work become second nature. (BIO 2010, 2003)
- One goal of this project is to provide greater flexibility in the premedical curriculum that would permit undergraduate institutions to develop more interdisciplinary and integrative science courses, as recommended in the BIO 2010 report. By focusing on scientific competencies rather than courses, undergraduate institutions will have more freedom to develop novel courses...(AAMC-HHMI report, 2009)

+ Can we teach physics to biologists in a way that adds value for them?

- What content should we teach?
- What are the barriers to constructing an effective course?
- What do we need to do to create effective inter- or trans-disciplinary instruction?

+ A speculation

- Achieving this inter-disciplinarity is going to be harder than it looks!
- Disciplines are disciplines for a reason.

+ Project NEXUS



- National Experiment
in Undergraduate Science Education
 - A 4-year \$1.8 M project
of the Howard Hughes Medical Institute
- Interdisciplinary science education
stressing competency building
 - UMCP (physics)
 - UMBC (math for bio)
 - Purdue (chemistry)
 - University of Miami
(capstone case study synthesis)

+ Interdisciplinary conversations

- As part of our role in project NEXUS, we have begun to hold extended interdisciplinary conversations.
 - A major task of each group is to negotiate with biologists the content and competencies on which the courses will focus.
- In addition, for a CCLI project, we have been interviewing biology students in a course in organismal biology that uses significant physics.

+ Discussants

■ Physicists

- Joe Redish
- Wolfgang Losert
- Catherine Crouch
- Jessica Watkins
- Chandra Turpen
- Ben Dreyfus
- Michael Fisher
- Peter Shawhan

■ Biologists

- Todd Cooke
- Jeff Jensen
- Karen Carleton
- Joelle Presson
- Kaci Thompson
- Marco Colombini
- Kristi Hall-Burke

■ Education Specialists

- Janet Coffey
- Dan Levin
- Jen Richards
- Julia Svoboda
- Gili Marbach-Ad

+ Some early observations

- These conversations have turned up differences among the professionals in the different disciplines (and even within the disciplines).
- Our interviews with biology students show expectations and perceptions of the disciplines that can affect how they react to “interdisciplinization”.

+ What does it mean to...

- ... *think like a physicist?*
- ... *think like a biologist?*
- ... *think like a chemist?*
- ... *think like a mathematician?*

+

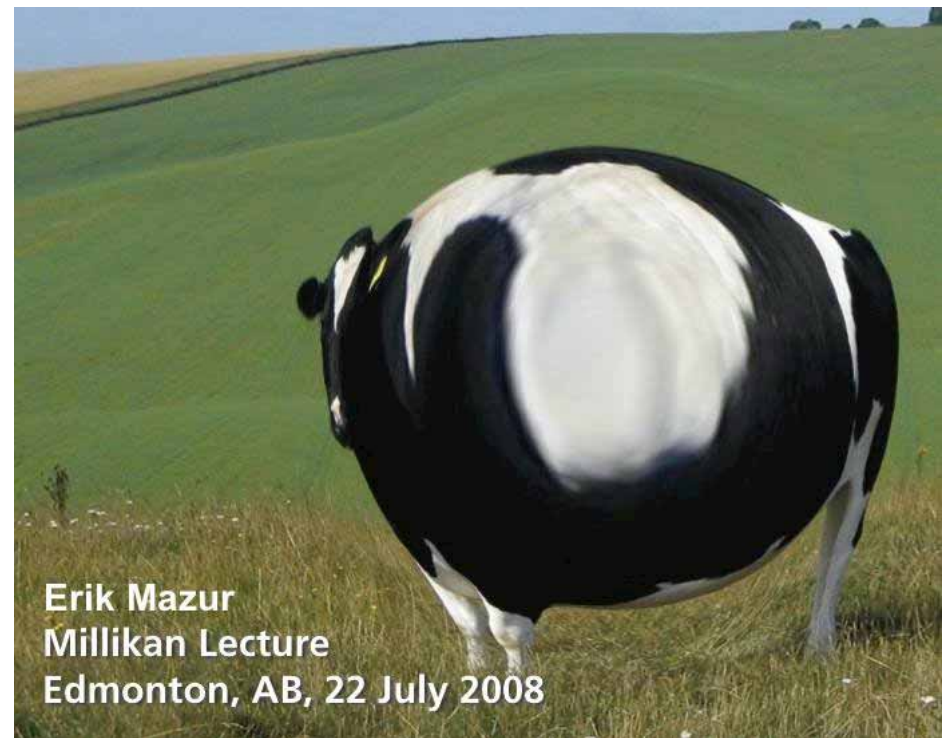
Physics

+ Conjecture

- One reason for the difficulty of getting more physics into bio and vice versa is epistemological – having to do with the nature and the structuring of the knowledge in the two professions.
- This plays out both in the attitudes of faculty and through student expectations.

+ Thinking about teaching physics...

- “Physics should be as simple as possible – but not simpler.” (Einstein)
- “The physics we are learning in this class is simple – but seeing that it is simple can be exceedingly difficult.” (Redish)



+ Physics simplicity

- We always seek to start with the simplest example and understand it thoroughly.
- This serves as the “stake in the ground” to use to organize our later thinking about more complex systems.
- We work from a few clear (nearly) universal principles and tie everything to them – often deriving dozens of equations from one starting point – plus assumptions about situations and initial conditions.

+ The first half of Physics I

$$\langle \vec{v} \rangle = \frac{\Delta \vec{r}}{\Delta t} \quad \langle \vec{a} \rangle = \frac{\Delta \vec{v}}{\Delta t}$$

Kinds of forces

- There are 2 classes of forces

- Touching

- » Normal — N (perpendicular to surface and pressing in)
- » Tension — T (pulling out of the surface)
- » Friction — f (parallel to surface — opposing sliding)

- Non-touching

- » Gravity — W
- » Magnetic — f
- » Electric — F

Causes of Motion: Newton's Laws

- **N0:** Objects only respond to forces acting on themselves, at the time the forces are exerted.
- **N1:** Objects change their velocity (perhaps =0) only if they are acted on by unbalanced forces.
- **N2:** Each object responds to the forces it feels by changing its velocity according to

$$\vec{a} = \vec{F}^{net} / m$$

- **N3:** When two objects touch, they exert equal and opposite forces on each other.

$$\vec{F}_{A \rightarrow B} = -\vec{F}_{B \rightarrow A}$$

Properties of Forces

- **Normal** — adjust to oppose compression (like a spring)
- **Tension** — t. force vs. t. scalar, analysis of the chain
- **Friction** — opposes sliding of surfaces over one another

$$T = k \Delta l$$

$$f_{A \rightarrow B} \leq f_{A \rightarrow B}^{\max} = \mu_{AB}^{\text{static}} N_{A \rightarrow B} \quad \text{not sliding}$$

$$f_{A \rightarrow B} = \mu_{AB}^{\text{kinetic}} N_{A \rightarrow B} \quad \text{sliding}$$

$$\mu_{AB}^{\text{kinetic}} \leq \mu_{AB}^{\text{static}}$$

- **Gravity** — towards the center of the earth, proportional to mass

$$\vec{W} = -\frac{GmM}{R^2} \hat{R} \approx m\vec{g}$$

12/18/09

Physics 121

+ **Physics tries to establish a simple core**

- Although there is a lot to do to interpret all this, it both ties to everyday experience and has a small number of ideas and relations that organize the complexity of the material.
- Bio looks different.

+ Does physics oversimplify?

- Pressure story
- Chemical energy?
- Should intro physics for biologists discuss chemical energy?
 - 1. Yes
 - 2. Maybe
 - 3. No



+ Physics

- 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 and model with math.
- Physicists think with equations.
- Introductory physics typically restricts itself to the macroscopic level and almost never considers chemical energy



+

Biology

+ Thinking about teaching biology...

- Biology seems irreducibly complex.
- Every living organism involves thousands of chemicals and tens of thousands of reactions. (More? OK)
- Biology has a “historicity” that physics lacks. It could, in principle, have happened some other way.

+ Problem

- Biological systems larger than the simplest viruses have complex structures at a multiplicity of levels.
- Even beginning to talk about a complex biological system requires learning a large new (and arbitrary) vocabulary.

Technical words in intro physics are often based on terms in everyday speech. While this causes some confusion, it also gives an interpretive foothold.

+ Pinky and the Brain



+ Biology

- 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).

+

Math

+ An epistemological difference with a practical implication!

- A big problem for our students – both for the physics majors and the math majors – is that the math in math class doesn't *look like* the math in their science classes.
- Math class math focuses on making the math they are learning as *clean and simple* as possible to the structure of the mathematical issue being discussed can be seen.
- Few instructors on either side seem to appreciate the cognitive load associated with seeing the “simple math” when it is imbedded in complex relationships.

+ **Disciplinary barriers: Math - Science**

- My physics colleagues teaching the majors have complained to me for many years that our math pre-requisites don't seem to be doing the job for our students. Why?

+ **Math as taught in math is not the math we need in science.**

- In physics we use math to compute solutions and to represent relationships.
- In bio, they use math largely to represent relationships and identify critical parameters.
- In math, well...

+ **From a math exam in a calculus course designed explicitly for bio majors**

The population density of trout in a stream is

$$r(x) = 20 \frac{1 + x}{x^2 + 1}$$

where r is measured in trout per mile and x is measured in miles. x runs from 0 to 10.

- (a) Write an expression for the total number of trout in the stream. Do not compute it.
- (b) ...

+ What do you think about this equation?

$$r(x) = 20 \frac{1+x}{x^2+1}$$

1. Please don't let them do this ever again!
2. It dislike it. It interferes with what I try to teach.
3. I don't mind it. It can be ignored.
4. You're making a fuss over nothing. Get a life!



+ To most physicists such an equation is deeply wrong!

- The numbers in the equation: “1”, “1”, and “20” represent three different kinds of physical objects that are measured in different ways.
- If European biologists decided to apply the equation, they are likely to measure x in kilometers rather than miles and get an incorrect answer.
- If the point of an equation is accurate communication, that equation is malicious. Instead of encouraging a precise interpretation, it explicitly encourages errors. (Sort of like using the same symbol to mean two different variables in the same equation.)

+ To most mathematicians fussing about units is wrong!

- The mathematicians I have spoken to about this brush it off. (anecdotal evidence – not research)
- They see the point of teaching the math to focus cleanly on the the structure of the mathematical relationships and the rigor (or at least the “honorable-ness”) of the proof.
- They are not used to thinking of the variables in their problems as measurements that have to be interpreted physically in order to make sense of an equation.
- Adding such an additional level of complexity distracts from the main point of teaching the math.

+ Furthermore, on this math exam

- There are 5 problems, each with 3-6 parts.
- There is no problem that contains even a single symbol representing a parameter.
- Every problem has a single letter representing an independent variable and a single letter representing a dependent variable.

I challenge you to find a single equation among the thousands of equations in an introductory physics text (or the dozen or so in an intro bio text) that satisfies these conditions!

+ Mathematics

- Mathematics is about mathematical structures and abstract relationships. It's not “about” anything physical.
- When we map physical meaning onto a mathematical structure, we inherit the mathematical tools that go with that structure – but that restricts our interpretation and freedom to use those tools.
- The transition to applications may be more challenging for students than those of us who have mastered the “hidden rules” of math-in-science might expect.

+ Implications of epistemological differences between disciplines

- Faculty in different disciplines don't communicate well concerning service courses – if at all.
 - When they do, they may not understand each other.
 - Service courses may not serve – or connect.
- Students taking courses in multiple disciplines may not understand why they need them.
 - They may “silo” – refusing to transfer.
 - They may resist efforts to bring in knowledge across disciplines

+

Building Bridges

+ Designing a physics course for biologists

- In designing a new physics class specifically for biologists we want the course to
 - contain physics content that is useful for bio instructors teaching upper division bio classes;
 - help students develop general scientific thinking and reasoning skills and competencies;
 - “feel” biologically authentic to the students in the class – that is, they see that learning this physics helps them make sense of and better understand important results they have learned in biology.

+ It's not so easy!

- A lot of critically important physics for biology is complex and relies on a lot of other physics.
 - We can't just do the groundwork and assume they will teach the later physics in upper division bio.
- A lot of critically important physics for biology relies on macro-micro connections.
 - We can't just stick to basic macro treatments.
- We need to figure out what to leave out as well as what to include!

+ 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.
- Rely on a familiarity with chemistry to include chemical energy and molecular modeling.

+ Physics / Biology Barriers: 1

- Even biologists who want to use physics in their bio classes might be satisfied in choosing bits and pieces and ignoring coherence and deep structure.
- “You don’t need to study forces in physics for biologists. Just teach energy.”
- “Most of the places where we need physics takes place in fluids where Newton’s laws don’t hold.”

+ Physics / Biology Barriers: 2

- Even biologists who want to use physics in their bio classes may reason with physics differently than physicists do.
- “The worm problem” – an example of trying to be authentic to both physics and biology in the first week of class (dimensional analysis and scaling).

+ Dimensional analysis, units, and scaling

■ Authentic physics

- One of the basic tools in “thinking like a physicist.”

■ Authentic biology

- Scaling and functional dependence plays a crucial role in a lot of biological processes.
- Rated of as one of the most important topics in physics in *Ratings of the Importance of Topics in the Natural Sciences, Research Methods, Statistics, and Behavioral Sciences to Success in Medical School* (AAMC, 2010).

+ **A problem posed
by a biologist for a bio class**



+ **Rewritten by a physicist
for a physics class**



+ What did we learn from this activity?

- Biologists and physicists look at things differently.
- These are not trivial differences.
- How will this play out with students?
- Students are aware of these differences early – indeed, sometimes they select their choice of science in part because of their perceptions of these differences.

+ Physics / Biology Barriers: 3

Biology students bring expectations to their physics and biology classes.

Ashlyn prefers silos

Ellen prefers staying concrete



+ 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 – the way we each look at knowledge.
- Student expectations can play a major role, yielded unexpected resistances and failures to connect.
- But it'll be fun, right?