Physical Sciences 2 and 3: Physics for the Life Sciences

Logan McCarty
Director of Physical Sciences Education
Harvard University

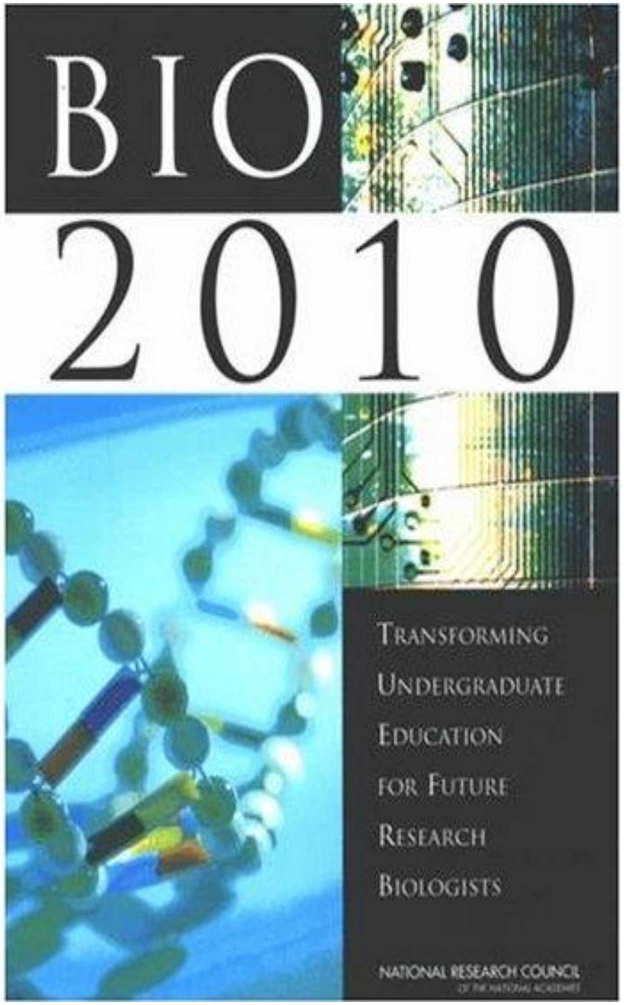
Report of the National Academy of Sciences, 2002

- What **physics** will be useful for the next generation of life scientists?

Physics

RECOMMENDATION #1.3

The principles of physics are central to the understanding of biological processes, and are increasingly important in sophisticated measurements in biology. The committee recommends that life science majors master the key physics concepts listed below. Experience with these principles provides a simple context in which to learn the relationship between observations and mathematical description and modeling.



Recommendations from the report of the National Academy of Sciences, 2002

- Physical Concepts for Life Scientists

Motion, Dynamics, and Force Laws

- Measurement: physical quantities, units, time/length/mass, precision
- Equations of motion: position, velocity, acceleration, motion under gravity
- Newton's laws: force, mass, acceleration, springs and related material: stiffness, damping, exponential decay, harmonic motion
- Gravitational and spring potential energy, kinetic energy, power, heat from dissipation, work
- Electrostatic forces, charge, conductors/insulators, Coulomb's law
- Electric potential, current, units, Ohm's law
- Capacitors, R and RC circuits
- Magnetic forces and magnetic fields
- Magnetic induction and induced currents

Conservation Laws and Gobal Constraints

- Conservation of energy and momentum
- Conservation of charge
- First and Second Laws of thermodynamics

Phys Sci 2

Phys Sci 3

Thermal Processes at the Molecular Level

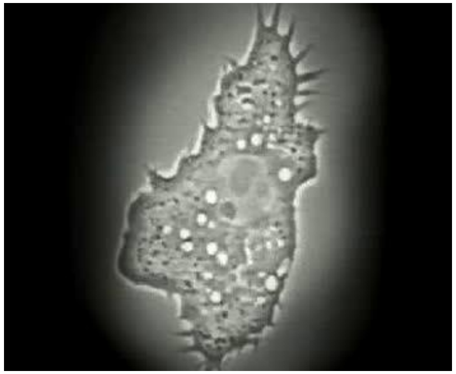
- Thermal motions: Brownian motion, thermal force (collisions), temperature, equilibrium
- Boltzmann's law, kT, examples
- Ideal gas statistical concepts using Boltzmann's law, pressure
- Diffusion limited dynamics, population dynamics

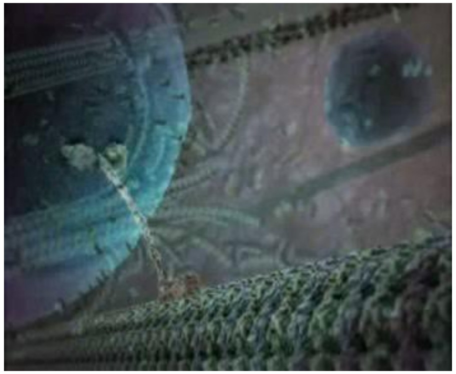
Waves, Light, Optics, and Imaging

- Oscillators and waves
- Geometrical optics: rays, lenses, mirrors
- Optical instruments: microscopes and microscopy
- Physical optics: interference and diffraction
- X-ray scattering and structure determination
- Particle in a box; energy levels; spectroscopy from a quantum viewpoint
- Other microscopies: electron, scanning tunneling, atomic force

Collective Behaviors and Systems far from Equilibrium

- Liquids, laminar flow, viscosity, turbulence
- Phase transitions, pattern formation, and symmetry breaking
- Dynamical networks: electrical, neural, chemical, genetic



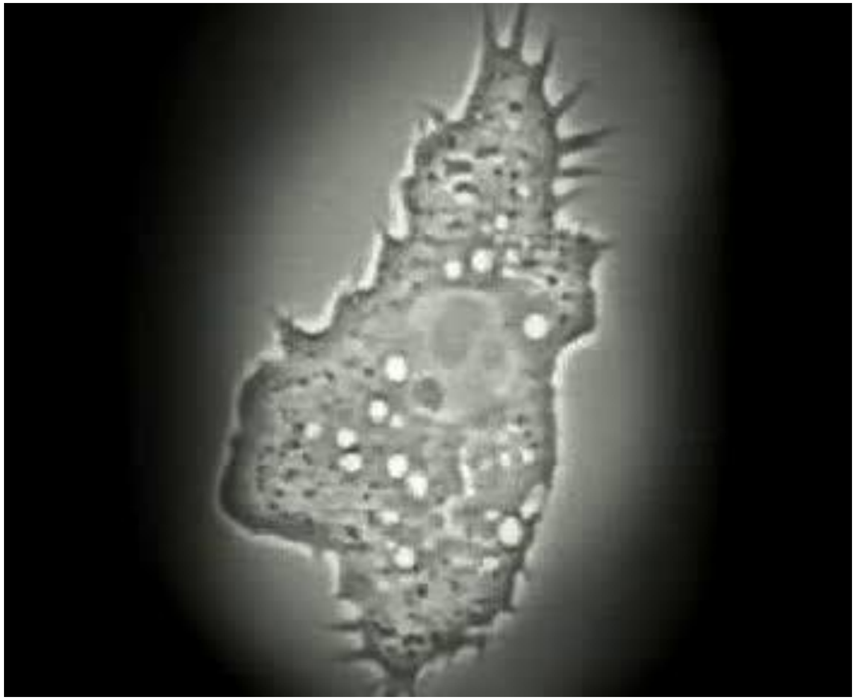



Physical Sciences 2: Mechanics, Elasticity, Fluids, Diffusion

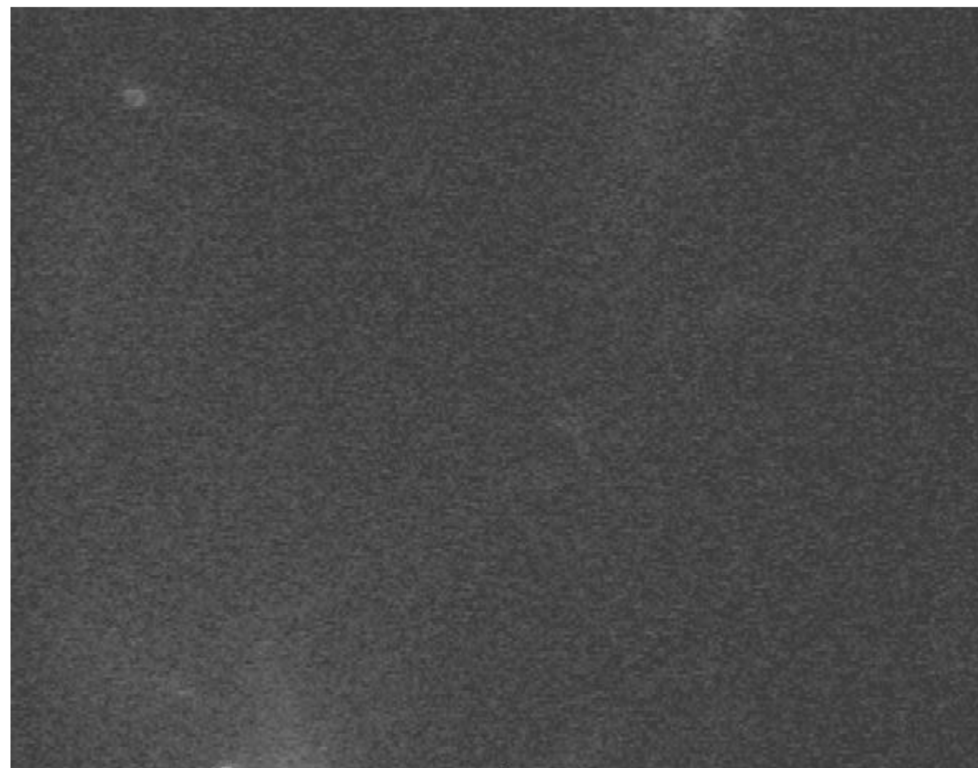
Goals:

- Show that physics is relevant to the life sciences
- Teach basic principles of physics (mechanics)
- Teach more topics in physics related to biology
- Show that learning physics can be enjoyable

Physics of the Cell

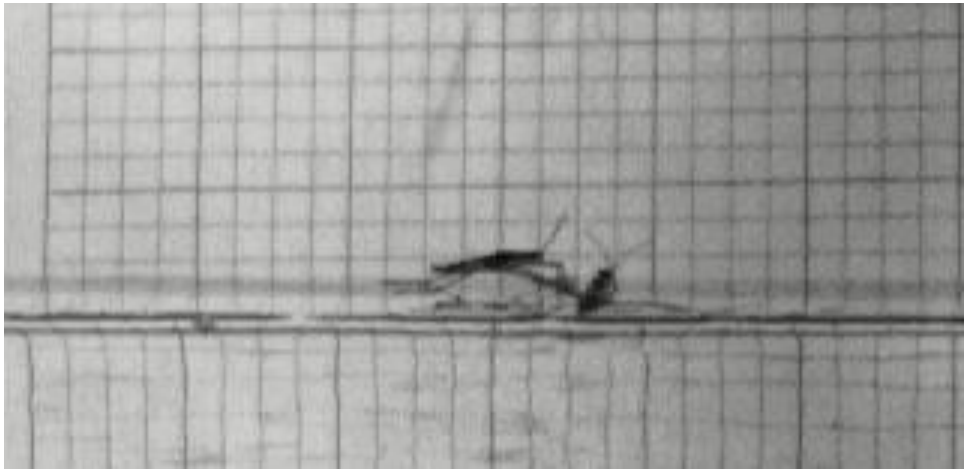


- Generate forces
- Change shape
- Swim and crawl



- Lots of physics here
- Cells aren't just sacks of biochemicals

Physics of Materials



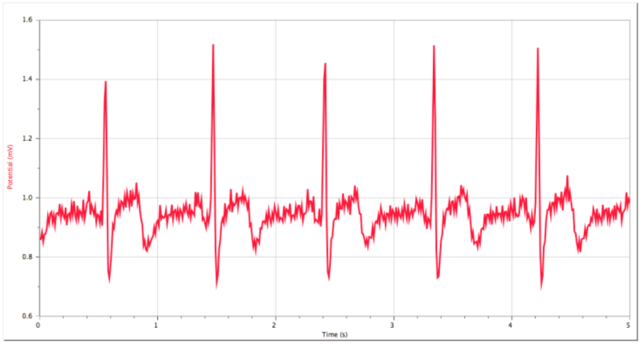
- How do material properties influence biological form and function?

- Elasticity
- Torsion
- Shear
- Viscosity
- Surface tension

Physical Sciences Laboratory

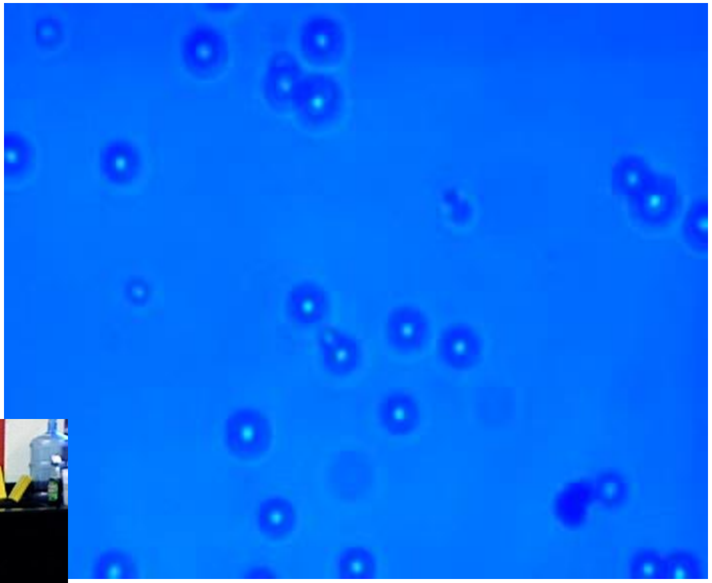
- ## Biologically-relevant physics

Periodic Motion: EKG Recording



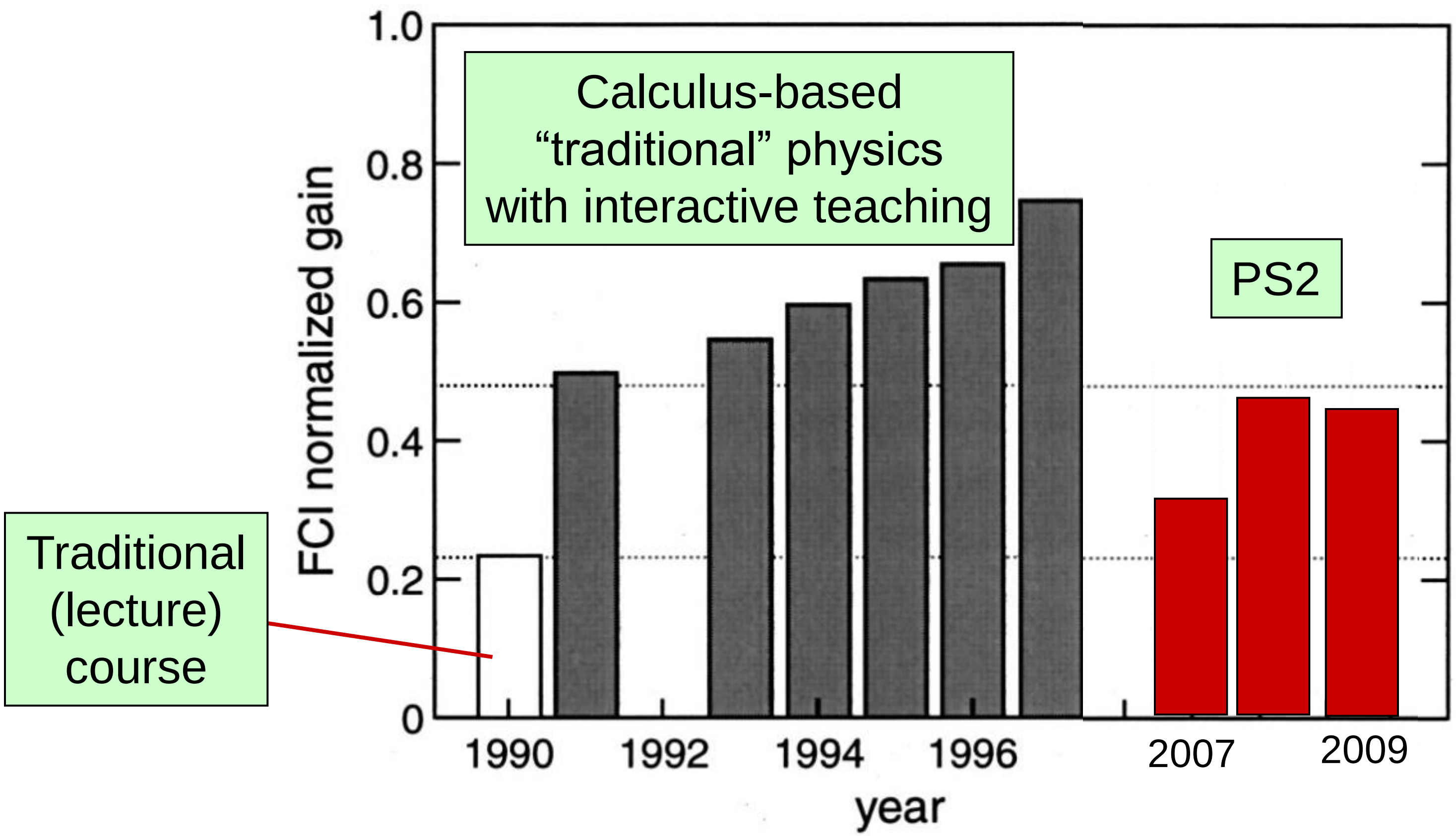
Forces and Motion: Jumping

Video Microscopy and Image Analysis: Measuring Brownian Motion



Goal: Teach basic principles of physics

- Compare pre-test and post-test scores on Force Concept Inventory



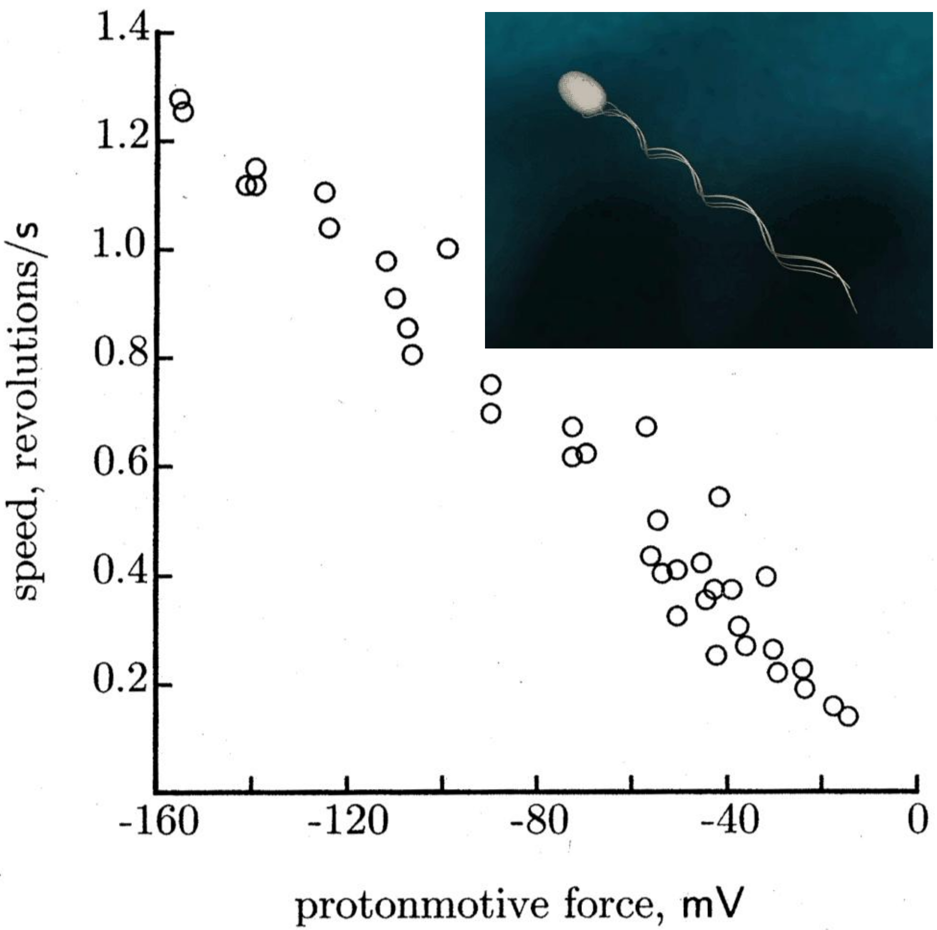
Crouch, C. E., and Mazur, E., *Am. J. Phys.*, **69**, 970 (2001)

No "gender gap" in student performance

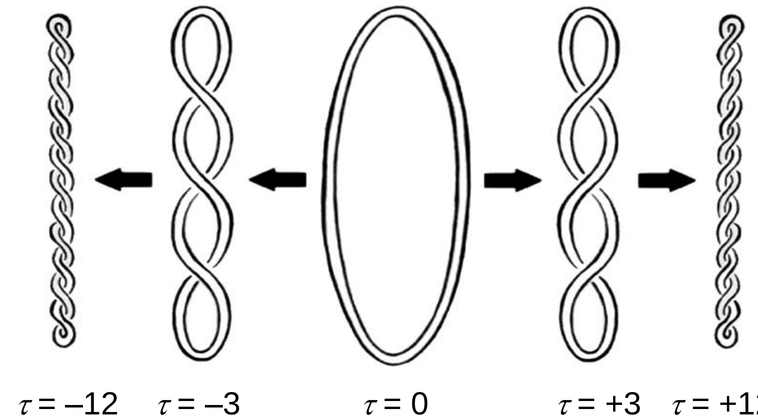
Goal: Teach physics related to biology

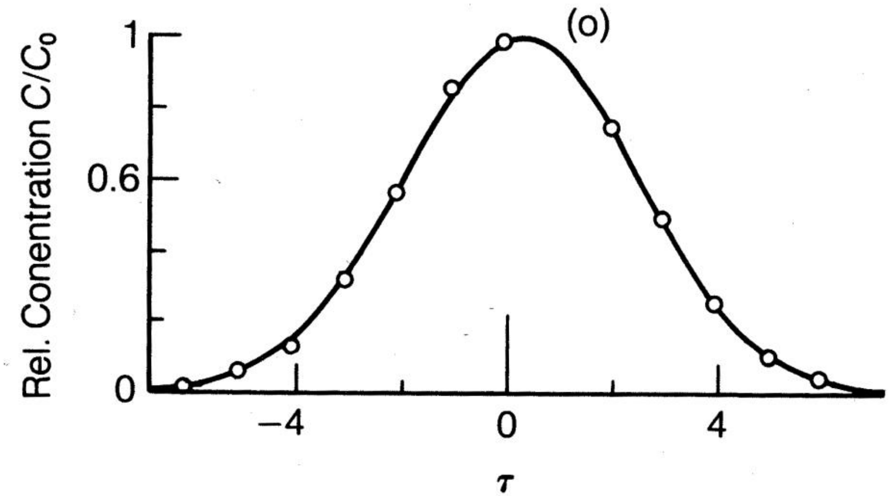
- Spend **five weeks** on fluids and statistical physics

Flagellar motor in *E. coli*



Superhelical turns in DNA

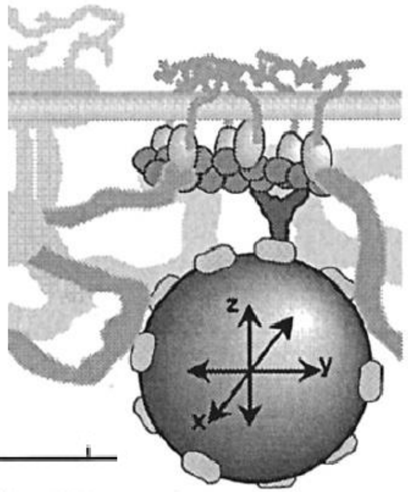


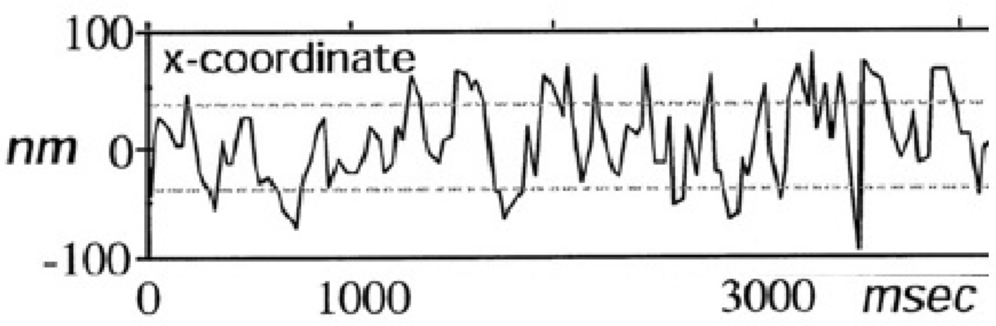


Goal: Teach physics related to biology

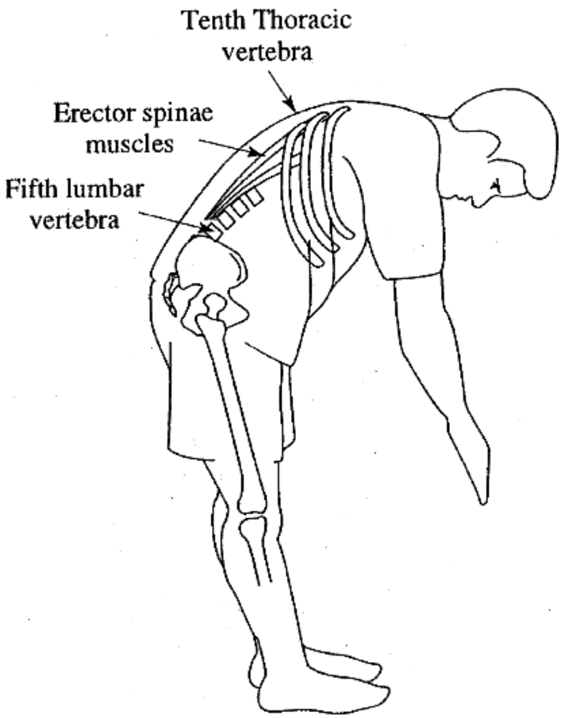
- Interpret recent research:

2008 final exam: Determine effective spring constant of cytoskeleton from the thermal motion of a nanoparticle





Discher, *Current Opinion in Hematology* 2000 7:117

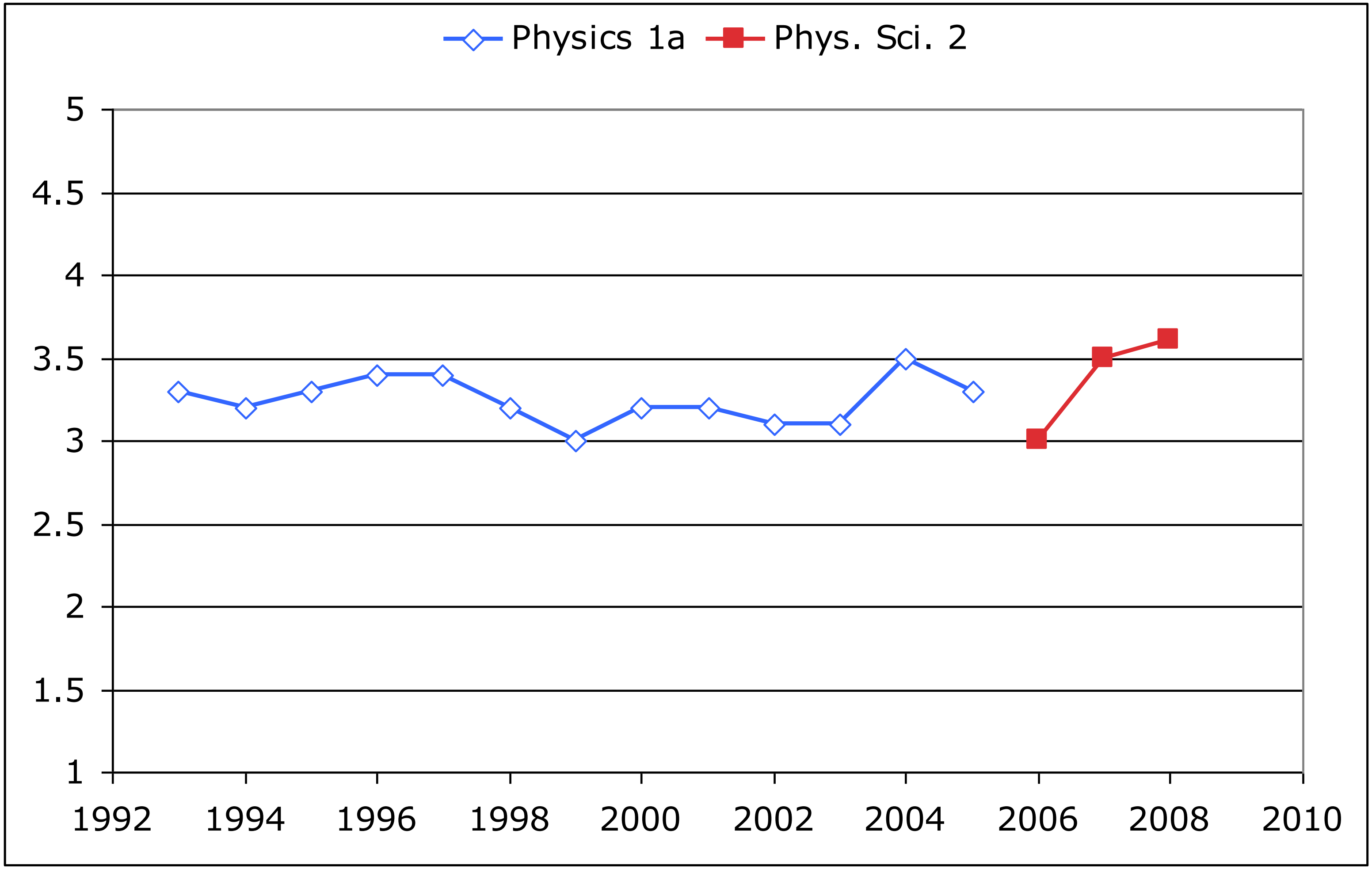


- Apply physics to biological problems:

Find force on 5^{th} lumbar vertebra

Goal: Learning physics can be enjoyable

- Student evaluations have improved since the introduction of Physical Sciences 2

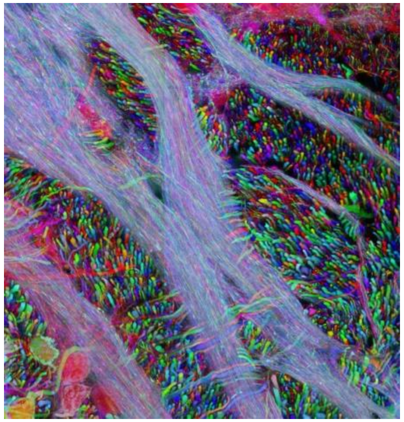


Goal: Show that physics is relevant

“What did you learn? How did this course change you?”

- Made me appreciate the integration of biology, medicine, and physics, and how physics operates in our everyday lives!
- Physics is not an intimidating cascade of equations, but rather a way of looking at and understanding the physical world.
- I apply physics to everything in the world. Every time I pour something or drop something, I'm thinking about physics.
- I saw why physics could be a medical school requirement.
- I actually approach the world differently now. For example, I hung something on a rack the other day and it started swinging, so I thought of torque and transfer of energy like a pendulum, etc. Then, when I came back a few minutes later, it was still swinging so I thought to myself: well, there must not be a lot of friction acting between those two surfaces. It was kind of cool actually.

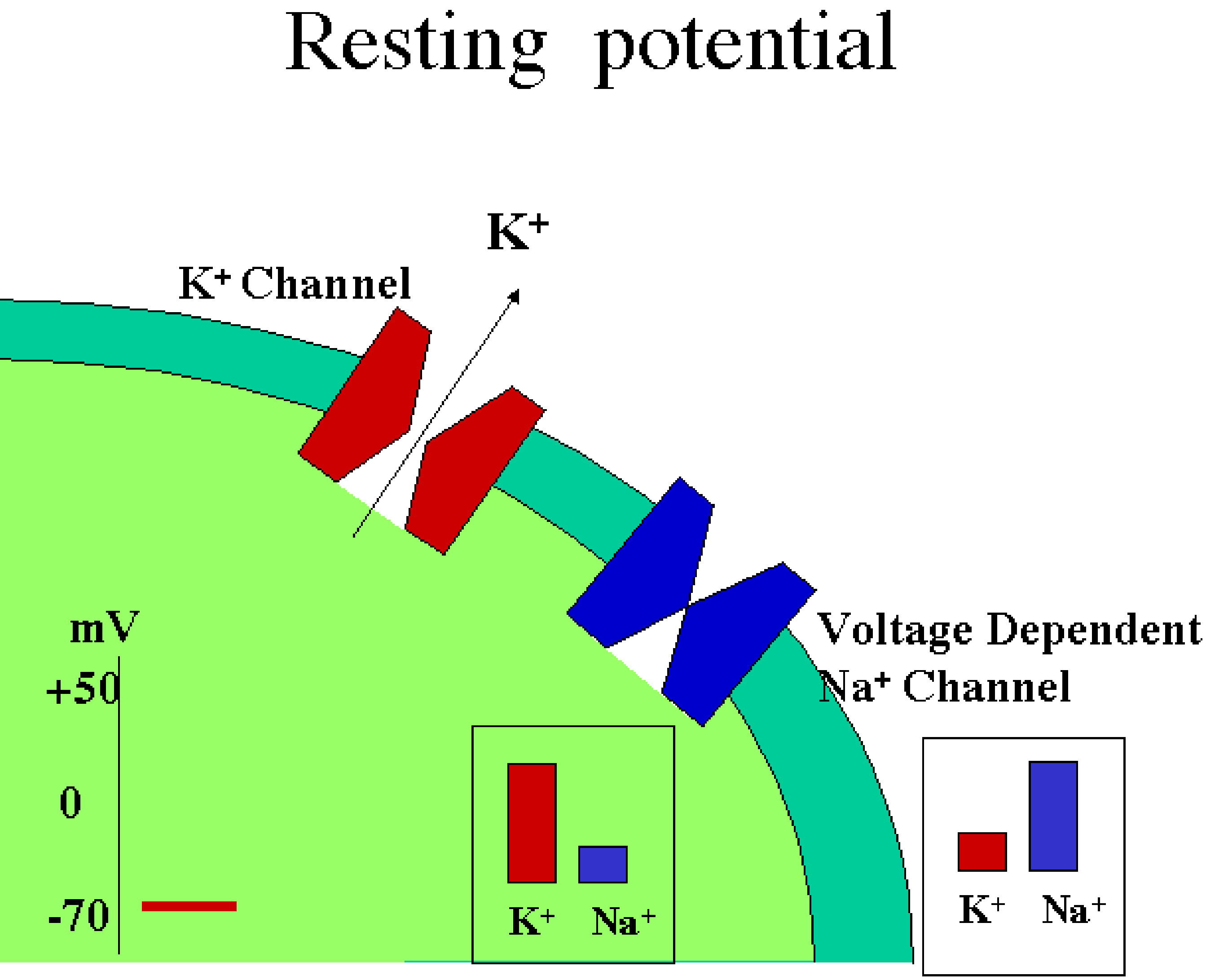


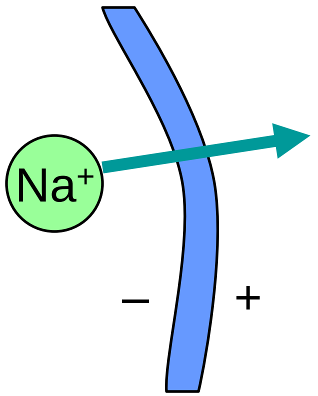
Physical Sciences 3: Electromagnetism, Waves, Imaging, and Information

Goals:

- Continuation of Physical Sciences 2
- Teach principles of E&M, waves, and optics
- Include relevant biological examples: microscopy, medical imaging (CT, MRI, etc.)

Electrical Potential in Cells



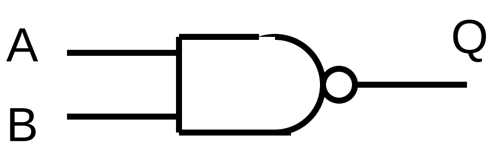


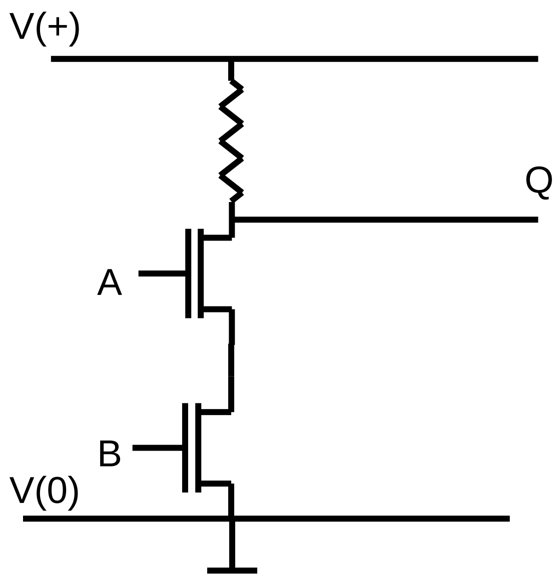
$$\frac{c_2}{c_1} = e^{-\frac{q(V_2 - V_1)}{kT}}$$

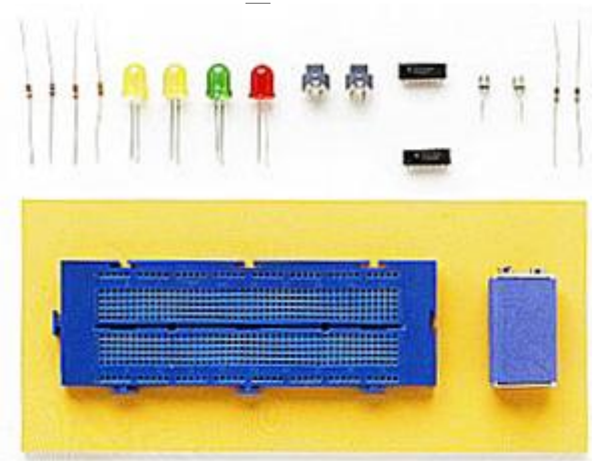
Digital logic: NAND gate

NAND (NOT AND)

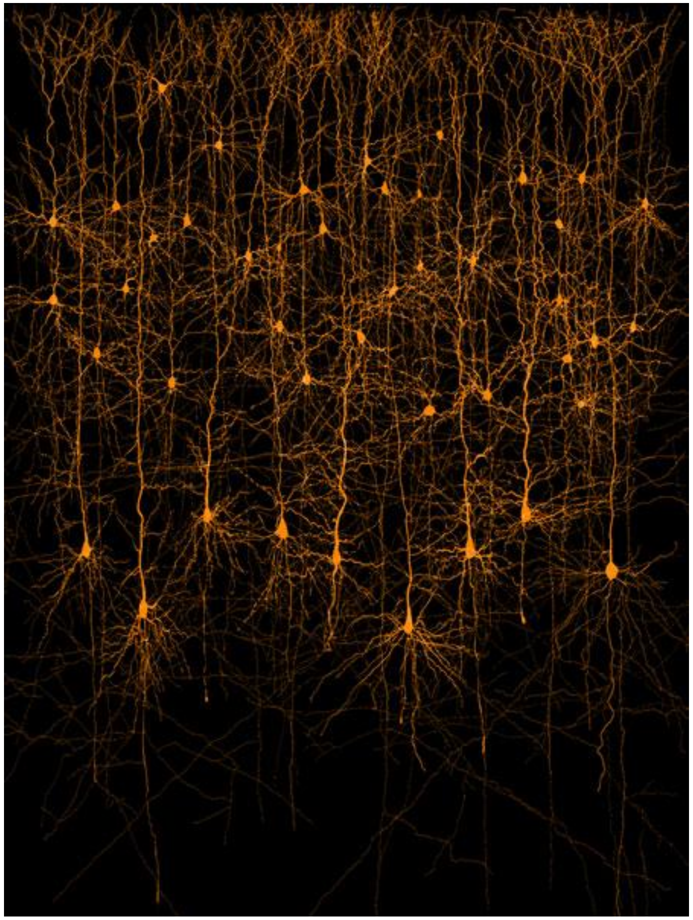
A	B	Q=NAND
0	0	1
1	0	1
0	1	1
1	1	0







Networks of neurons for processing information

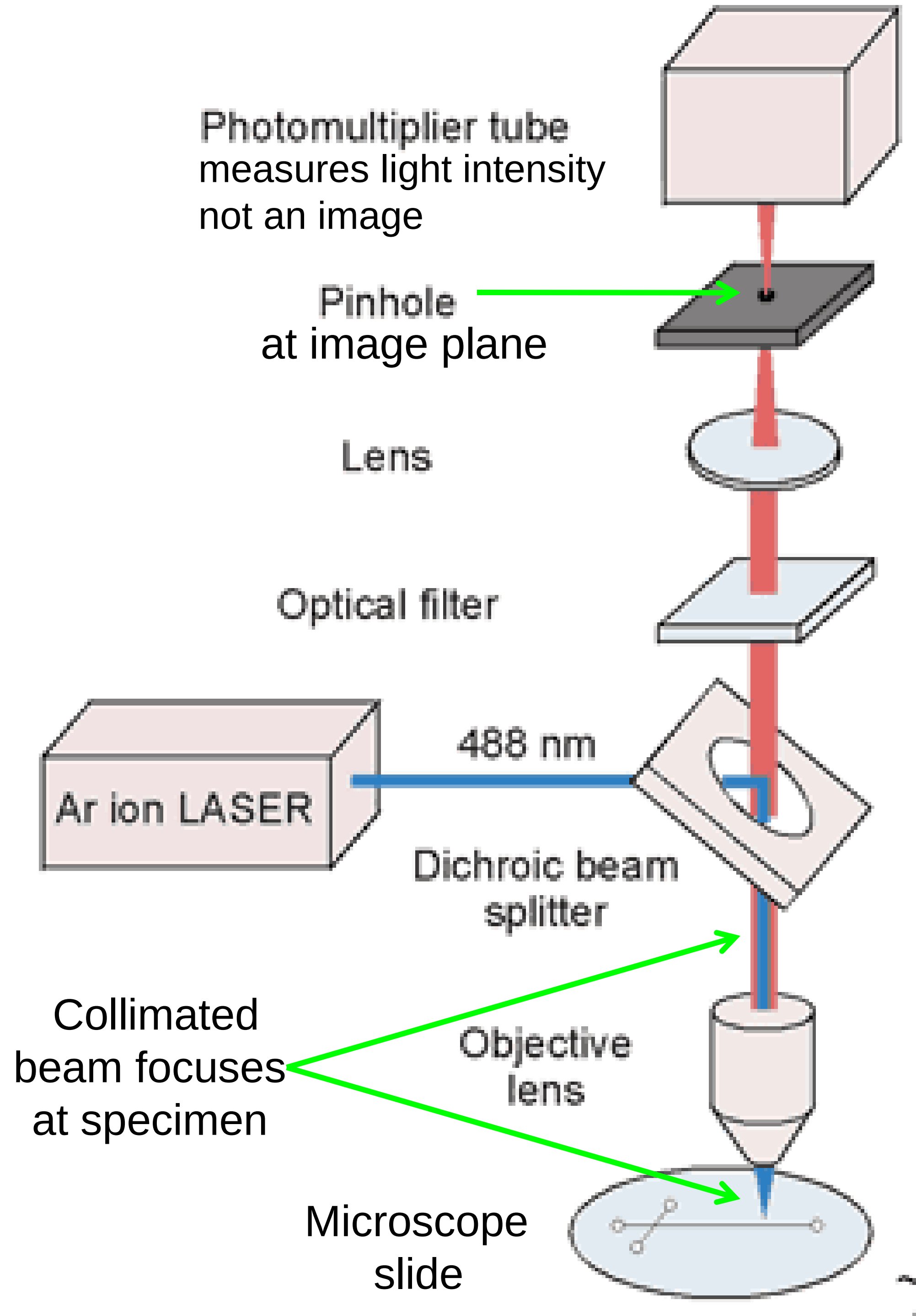


Medical Ultrasound

Two-photon Confocal Microscopy:

"Putting it all together" in PS3

- Light
- Ray optics (lenses)
- Wave optics (diffraction limit)
- Two-photon fluorescence



How to incorporate broader learning goals into the curriculum?

Broad Goals for Physics Concentrators

Surveyed the physics faculty:

"Everyone who leaves Harvard with an undergraduate degree in physics should be able to . . ."

Received over 100 suggestions; grouped into six broad categories

Broad Goals for Physics Concentrators

- **Physical reasoning** (order of magnitude, dimensional analysis, scaling laws)
- **Quantitative analytical techniques** (computation, data analysis, statistics)
- **Scientific methodology** (modeling, connecting theory and experiment)
- **Communication** (writing and presentation skills)
- **Independent learning** (ultimately, ability to learn from the primary research literature)
- **Broader impact of physics** (applications, ethical considerations, current frontiers)

Similar Goals: Carleton College

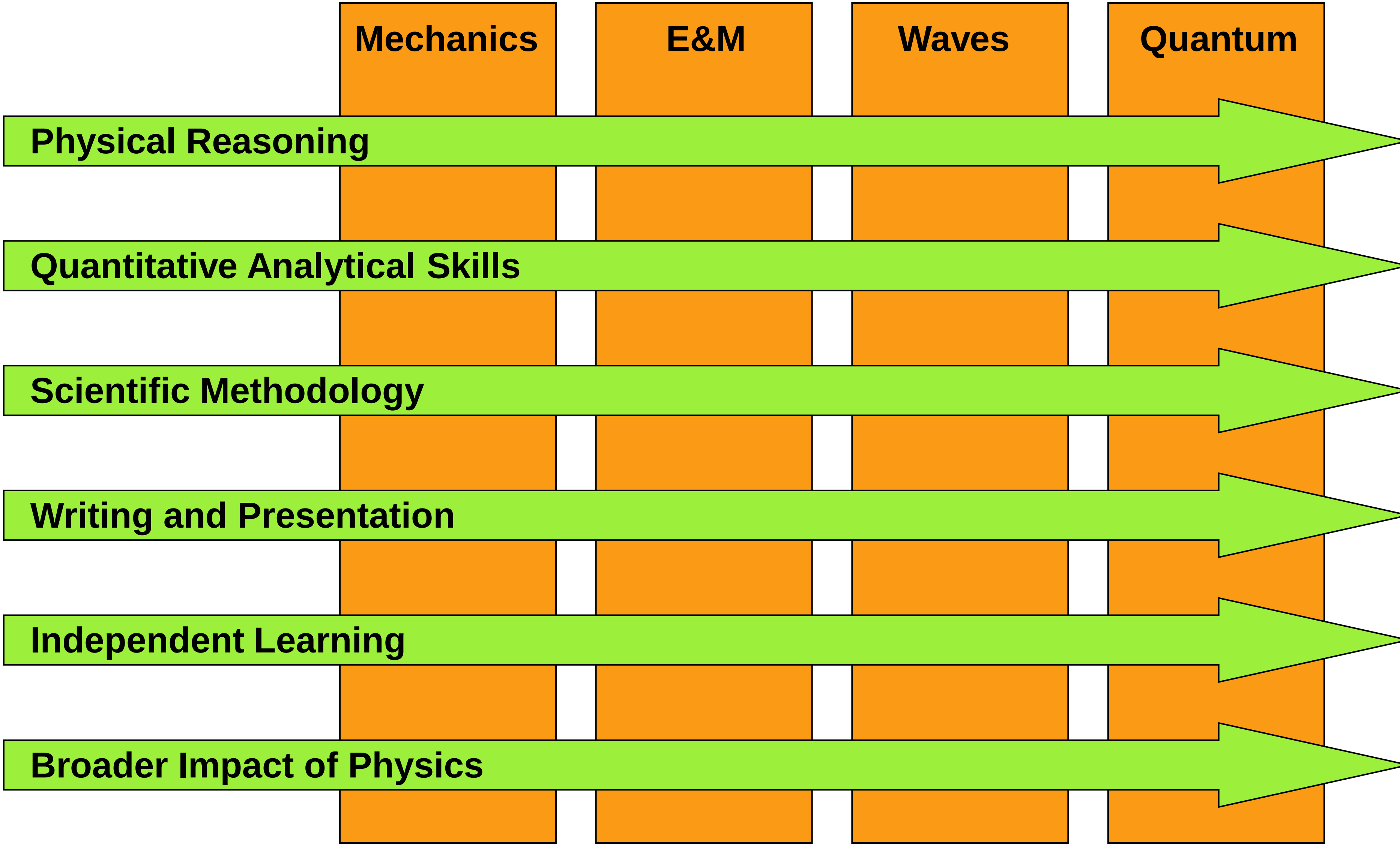
Carleton College: Undergraduate Physics Goals

We expect our students, both majors and non-majors, to develop a number of **skills** while taking physics courses. Some of these are general skills: the ability to communicate clearly in **written work and oral presentation**; the ability to locate information through **library research** and other means; the ability to continue **learning on a largely independent basis**. Especially relevant to majors are skills in logical **problem-solving and mathematical analysis**, **experimental design and the use of measurement apparatus**, and the **use of computers in modeling physical phenomena and for data acquisition and analysis**.

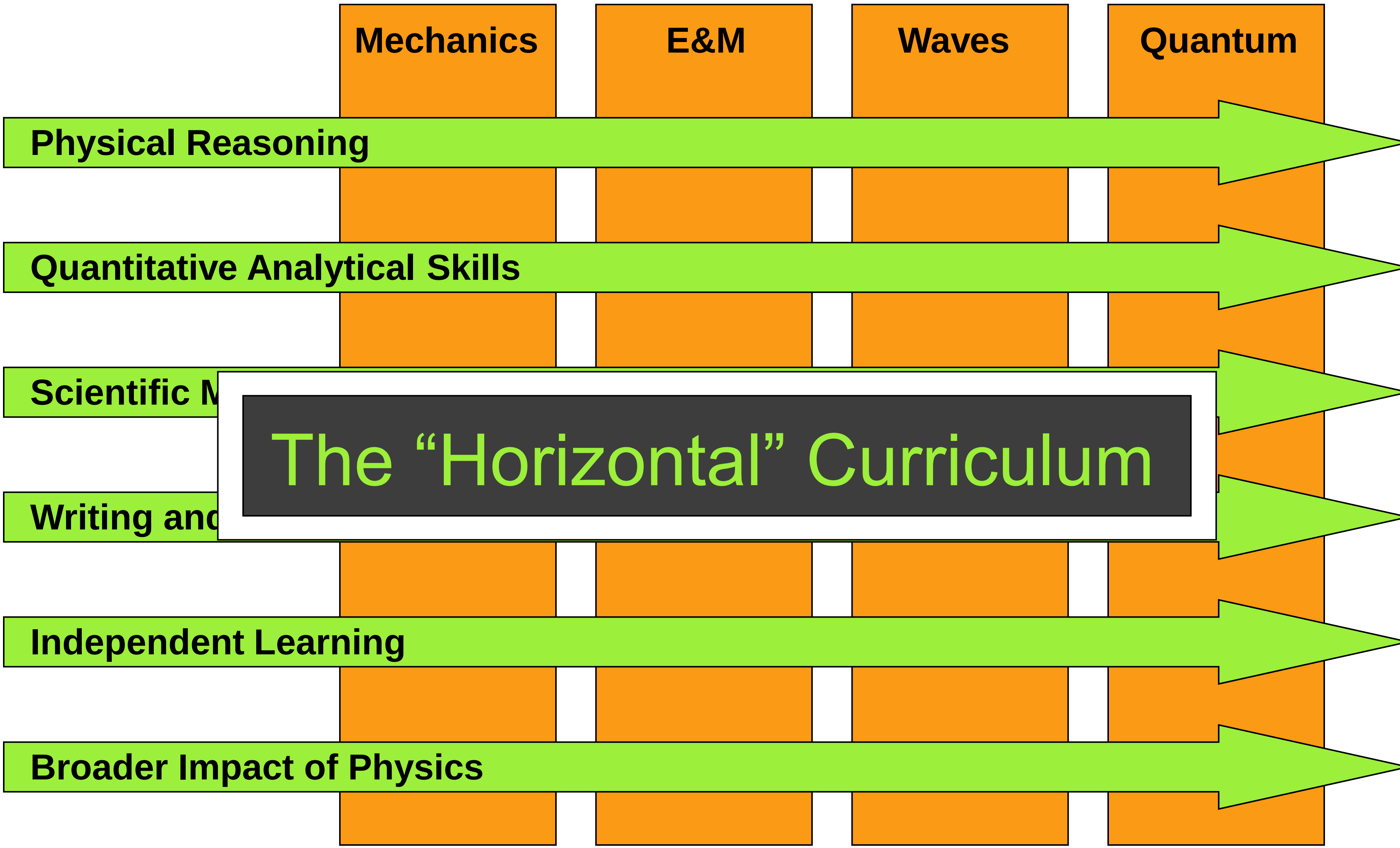
How to teach these skills?

Mechanics	E&M	Waves	Quantum

How to teach these skills?



How to teach these skills?



How to teach these skills?

- “Horizontal” curriculum needs clear learning objectives and detailed syllabus
- Assign faculty to teach the horizontal curriculum, with regular teaching credit
- Ideally, use cohort model: instructor follows students through 4 semesters

Acknowledgments

- Physical Sciences 2 and 3:
  Melissa Franklin
  Howard Stone
  Vinothan Manoharan
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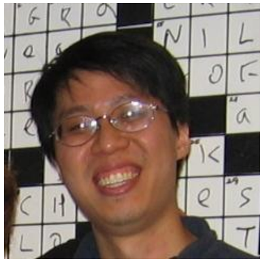
  George Whitesides
  Joon Pahk
  Timothy French








- Broader learning goals:
  Christopher Stubbs
  Amir Yacoby