Teaching Introductory Physics in Biological Context

Catherine H. Crouch, Swarthmore College

AAPT session BF

15 July 2013

SWARTHMORE

Today's talk

- Responding to the needs of life science/pre-health students (IPLS):
  "physics in biological context"
- Essentials of Swarthmore's implementation
- Outcomes: engaging student interest
- Future directions

SWARTHMORE

Collaborators and colleagues

- Fai Wisittanawat ’13 and Ann Renninger (Swarthmore)
- Ken Heller (University of Minnesota)
- University of Maryland NEXUS group
- Tim McKay (University of Michigan)
- Mark Reeves and Rob Donaldson (GWU)
- Suzanne Amador Kane (Haverford)
- Dawn Meredith (University of New Hampshire)
- Ralf Widenhorn (Portland State University)
- …. And many more!

SWARTHMORE

- In pure water, double-stranded DNA tends to separate into two strands, but in salt water, it stays together. Explain why in terms of the electrical interactions between the charged molecular backbones.

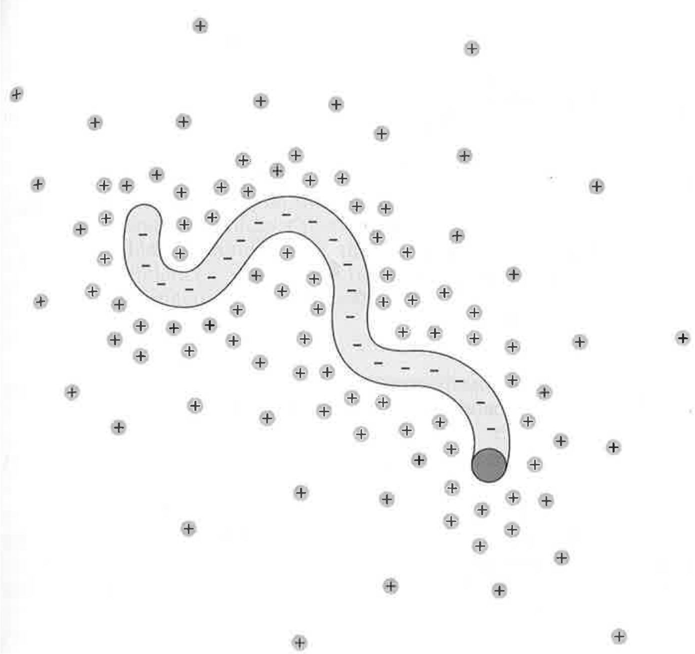
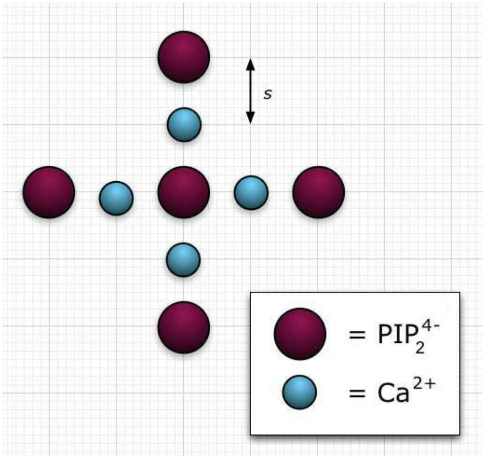


Figure 9.14 DNA in an ionic solution. The schematic shows the large negative charge density on the DNA molecule and the positive counterions in the surrounding solution.

- Rare, highly negatively charged lipids need to cluster on the cell membrane surface for certain cellular processes. These clusters include small positive ions. Using the simple model of a cluster provided, show that the electric force on the bottom lipid is attractive with doubly charged Ca^{2+} ions but not with singly charged Na+ ions.



Based on work by Wang, Collins, Guo, Smith-Dupont, Gai, Svitkina, and Janmey, 2011.

SWARTHMORE

Common approaches of IPLS

- Organize around "authentic" life science contexts

Watkins, Hall, Coffey, Cooke, and Redish, PRST-PER 2011.

SWARTHMORE

Goals of IPLS course

Students:

- Learn most important physics content
- Gain scientific skills: modeling, rigorous qualitative reasoning, quantitative data
- Become ready and motivated to apply these tools in their future work

SWARTHMORE

Common approaches of IPLS

- Organize around “authentic” life science contexts
- Focus syllabus on most important topics
- Emphasize modeling skills
- Communicate explicitly that physics is integral to the life sciences

SWARTHMORE

Implementation at Swarthmore

SWARTHMORE

Course material

- All students take standard 1st semester of university physics
- Both standard and IPLS 2nd semester courses offered: waves, optics, E&M

SWARTHMORE

Course material

- Modified syllabus
  - Expand electrostatics in media, circuits, optics
  - Omit Gauss's Law and AC circuits
  - Greatly reduce magnetism (focus on magnetic dipoles interacting with magnetic fields)
  - Minimize induction (Faraday's Law, Lenz's Law)
- Organize each topic and unit around one or two biological contexts
  - Optics: confocal microscopy and human vision
  - Electricity (including circuits): nerve signaling
  - Induction: Pacemaker safety

SWARTHMORE

Sound pedagogy

Utilize physics education knowledge base:

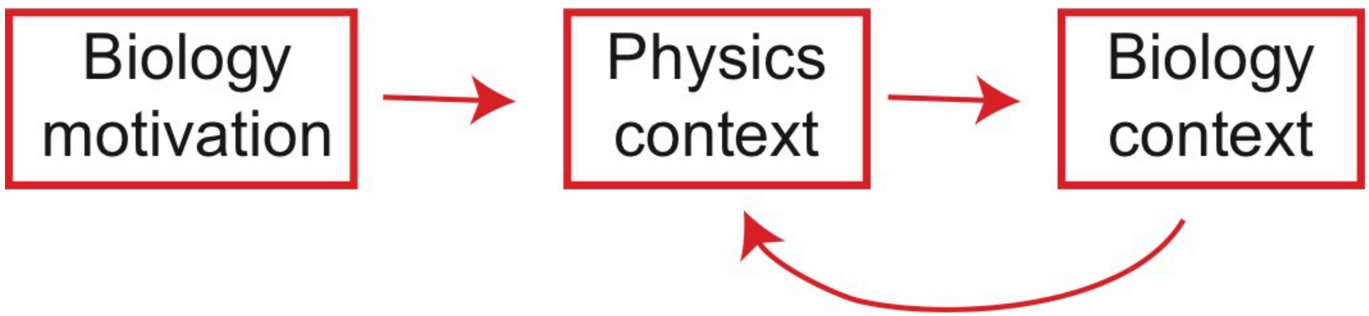
- Emphasize both qualitative reasoning and quantitative problem solving
- Peer Instruction lecture
- Weekly problem-solving laboratory

Adapt existing validated materials whenever possible!

PI: Crouch, Watkins, Fagen, & Mazur (2007). CGPS: Heller & Heller (2004). Redish, Teaching Physics with the Physics Suite (Wiley, 2003)

SWARTHMORE

Physics in biological context



- Physics must give students real insight into biology contexts
- "Goldilocks" contexts are critical!
- Connect to specific courses/experiences
- Both biology ("macro" and "micro") and instrumentation

SWARTHMORE

Expansive framing

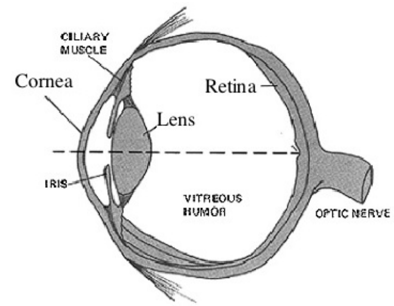
- High school biology students tutored about circulatory system
- Two different “framings”:
  - Restricted to the class
  - Broadly relevant and applicable
- In subsequent lesson on respiratory system, examined whether students could apply prior lesson
- Students who received broadly relevant (“expansive”) framing were more successful

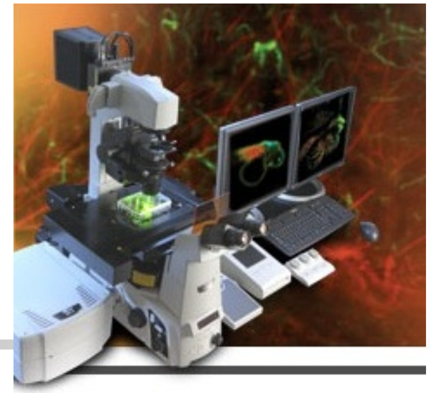
Engle, Nguyen, and Mendelsohn, Instructional Science 39, *603 (2011).*

SWARTHMORE

What does this look like?

Ray optics





- Usual physics approach:

  move object or lens with fixed *f*

  → moves image
- Human vision: fixed retina, adjustable lens

  (microscopes too)

SWARTHMORE

ConcepTest: biological context

You are in a garden initially looking at a nearby flower. If you then turn your gaze to a tree that is farther away, how does the focal length of your eye's lens change, if at all?

1. The focal length increases.
2. The focal length decreases.
3. The focal length remains the same.
4. Need more information.

SWARTHMORE

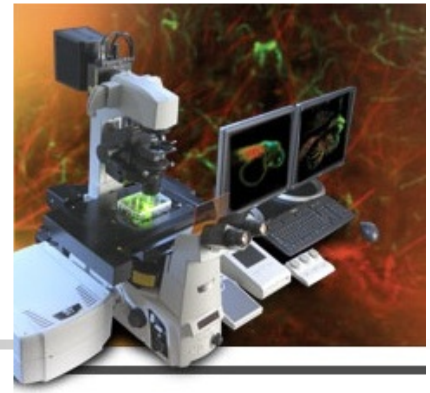
ConcepTest: biological context

You are in a garden initially looking at a nearby flower. If you then turn your gaze to a tree that is farther away, how does the shape of your eye's lens change, if at all?

1. The lens becomes rounder (more curved).
2. The lens becomes flatter.
3. The lens shape remains the same.
4. Need more information.

SWARTHMORE

Microscopes

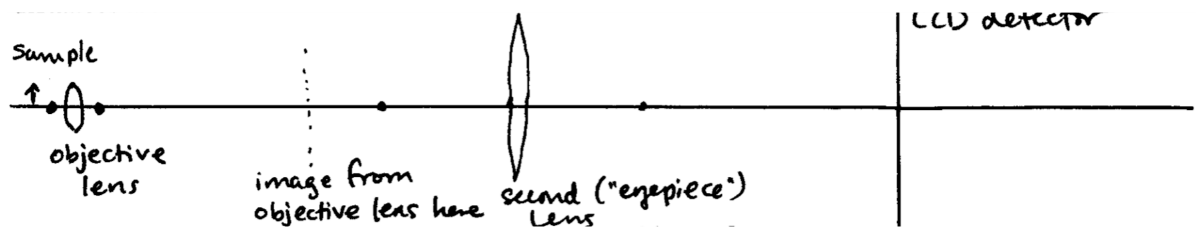


- Usual physics textbooks:
  - antiquated compound microscope design
  - formula-driven
- Instead: teach students to analyze images formed with multiple lenses

SWARTHMORE

Biological context problem

You are using a microscope that produces an image recorded by the light-sensitive detector of a CCD camera. The microscope has a 40x objective lens and a second +10 cm focal length lens giving 2x additional magnification. The figure showing the optical arrangement is **not** to scale.



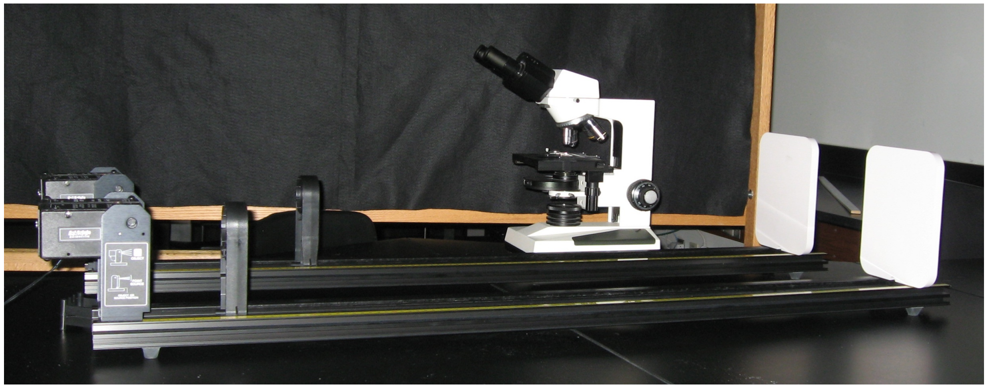
(a) Is the image on the detector real or virtual? Upright or inverted (relative to the sample)?

(b) If the sample is 2.0 mm from the objective when the final image is in focus, how far is the detector from the objective lens?

SWARTHMORE

Labs: optical instruments

- Explain magnification of different microscope objectives in terms of *f*, *o*, and *i*
- Constructing a two-lens microscope to produce either a real or a virtual image



SWARTHMORE

Does the course succeed?

Outcomes: student attitudes

- Very positive course evaluations
- High enrollment

2012 course evaluation

At the beginning of this course, I expected physics to be:

Response	Average	Total
very useful in understanding the life sciences	21%	14
somewhat useful in understanding the life sciences	57%	38
of little use in understanding the life science	24%	16

SWARTHMORE

2012 course evaluation

Now at the end of this course, I consider physics to be:

Response	Average	Total
very useful in understanding the life sciences	55%	37
somewhat useful in understanding	43%	29
of little use in understanding the life science	1%	1
of no use in understanding the life sciences	1%	1

Replicated in 2013 (zero "of no use" responses)

SWARTHMORE

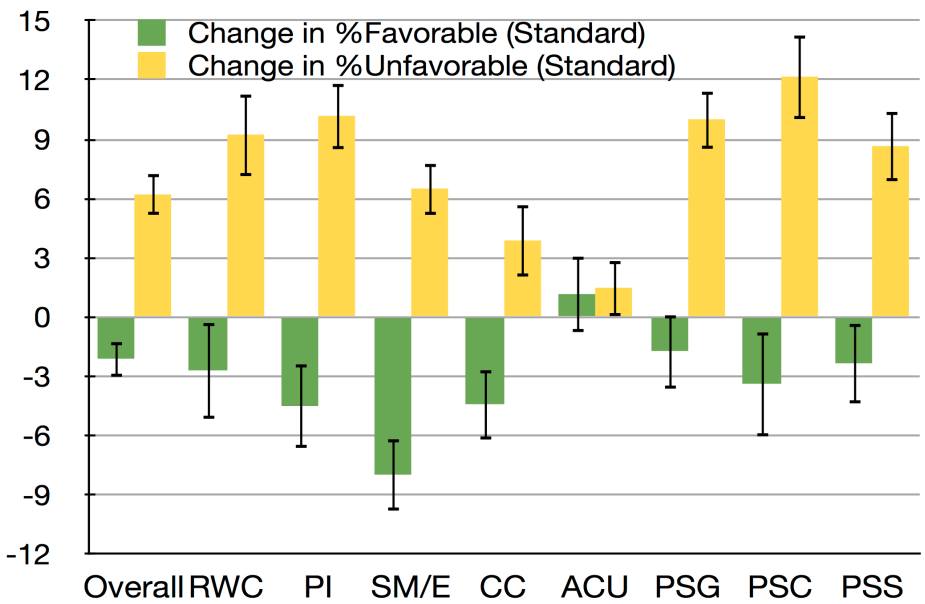
Outcomes: attitudes/beliefs

- Colorado Learning About Science Survey (CLASS): measures a set of attitudes and beliefs about learning physics
- Series of statements rated “strongly disagree” to “strongly agree”
- Give survey (pre and post) in both standard first semester and IPLS second semester

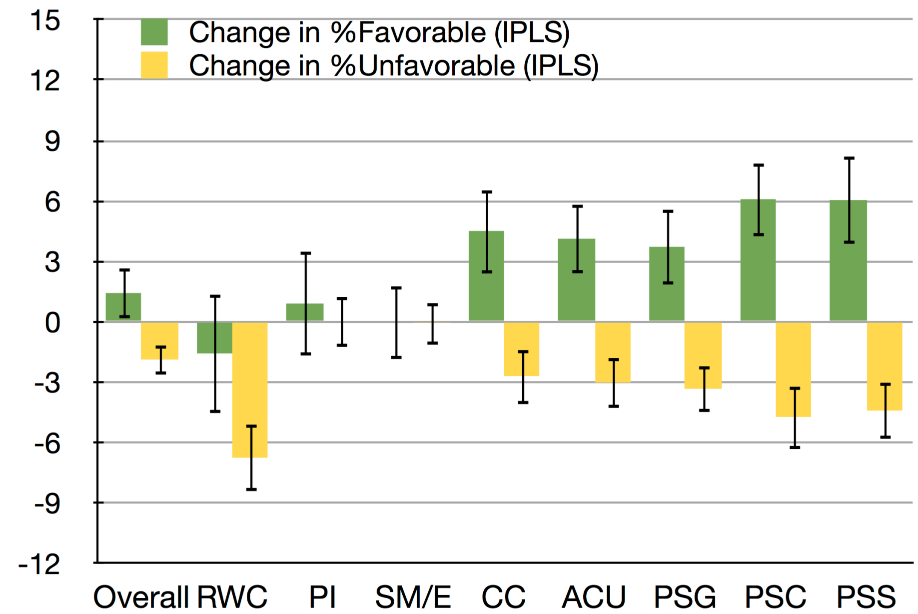
SWARTHMORE

Changes in CLASS

Standard first semester



IPLS second semester



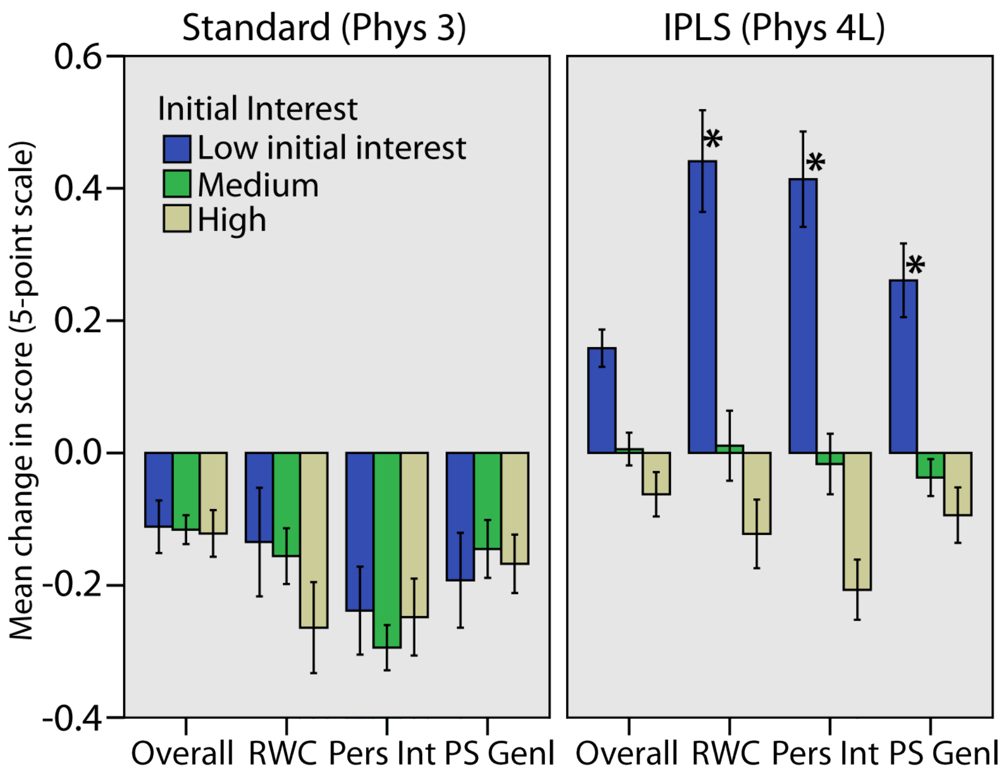
Attitudes decline in standard course, hold steady/slightly improve in IPLS course

SWARTHMORE

Prior interest metric

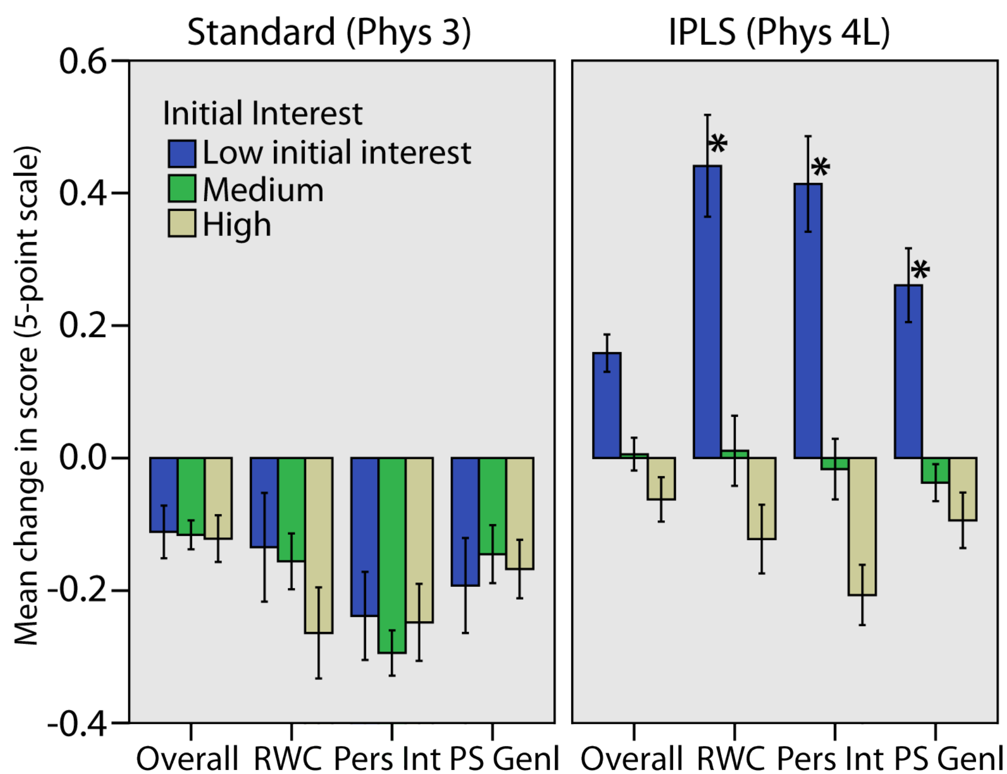
- Used subset of CLASS pre-survey items to determine students' initial interest in physics

CLASS changes by initial interest



SWARTHMORE

CLASS changes by initial interest



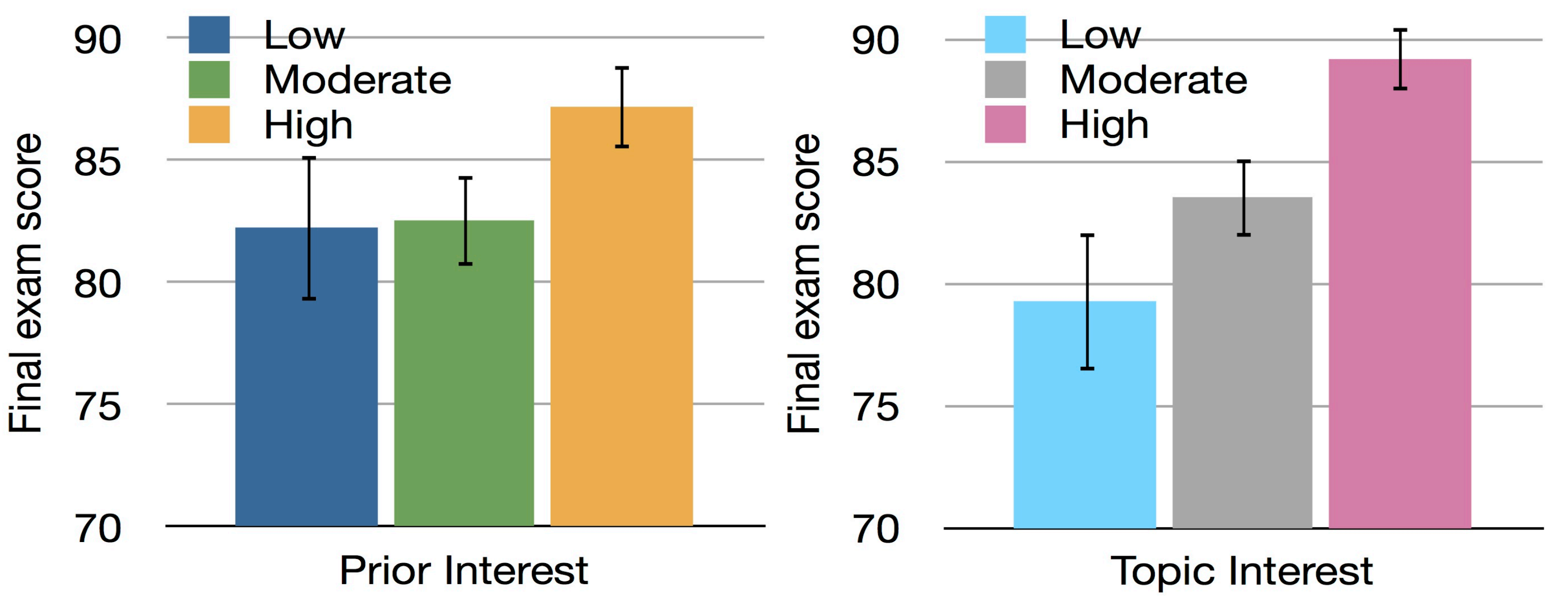
Students who come in with low interest improve significantly
Not repeated in 2013 (small numbers)

Metric for topic interest

- Students rated biological examples by interest level
- Determined overall student level of interest in biological examples (not physics)
- Influenced by, but not identical to, prior interest

SWARTHMORE

Topic interest matters!



Topic interest, more than prior interest, predicts final exam score (p < 0.05)

SWARTHMORE

Course evaluation comments

- "I often found myself thinking, 'Oh, so that's how it works,' because I'd never really thought about the physics behind some of the biological concepts I'm very familiar with." (Junior biology major)
- "I liked having a physics class that was geared toward including some biology…[In the past] I didn't see the direct connections with the real world and how I could apply physics. This class has helped me see just that." (Junior biology major)
- "The applications to biology that were covered only in class (not in the book) were the most interesting part of the class." (Sophomore chemistry major)

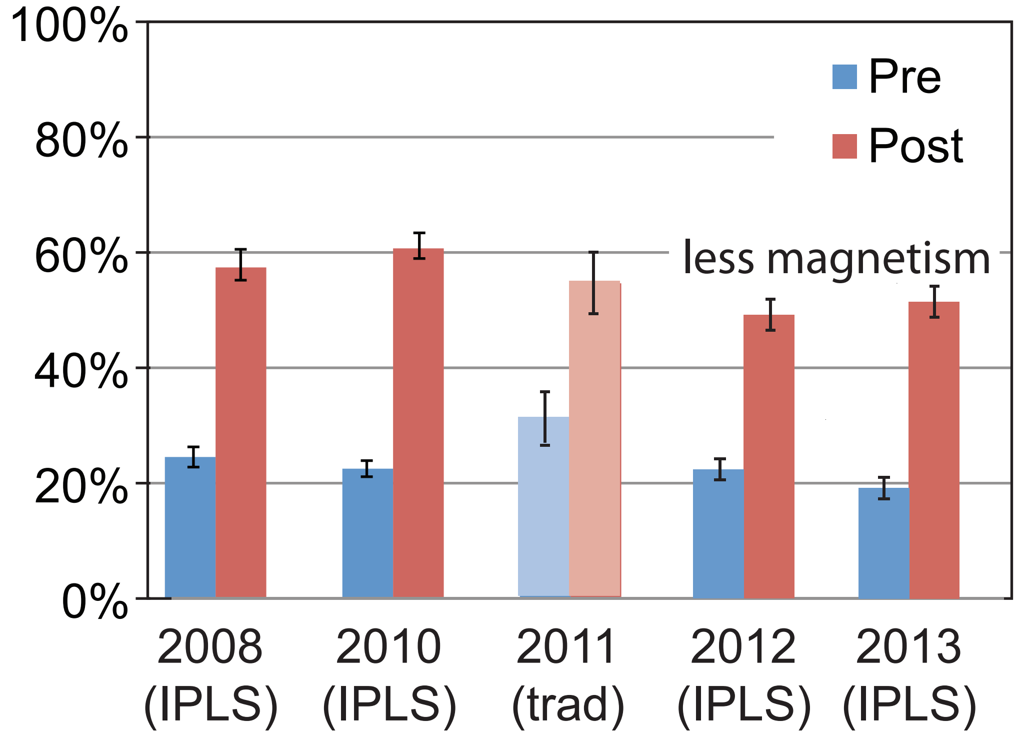
SWARTHMORE

Email from student

- "I wanted to tell you how well Physics 4L prepared me for my summer …. All of the [work] we did modeling the cell membrane as a capacitor and the discussions we had about neurons as parallel circuits really prepped me for the more complicated things I have been doing here. Recently I've been calculating currents through membrane potassium and sodium channels and accounting for leakage." (Junior biology major)

SWARTHMORE

Outcomes: BEMA



- Omit questions on transformer, induced E
- Similar or better scores to traditional course

SWARTHMORE

Future directions

- Closer investigation of effects of prior interest and topic interest
- Find ways to engage higher interest students
- Better instruments to examine content learning
- Investigate whether students do take physics into future work

SWARTHMORE

Thanks to …

- HHMI and Mellon grants to Swarthmore
- Ann Renninger and Fai Wisittanawat '13
- Ann Ruether
- Many colleagues at Swarthmore and elsewhere
- University of Maryland NEXUS group

Course materials available at http://materials.physics.swarthmore.edu/iplsmaterials

SWARTHMORE

SWARTHMORE