Optimizing Introductory Physics for the Life Sciences: Placing Physics in Biological Context

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Today’s talk

- Responding to the needs of life science/pre-health students (IPLS):
  “physics in biological context”
- Essentials of Swarthmore’s implementation
- Outcomes: content learning and engaging student interest
- Future directions

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Collaborators

- Fai Wisittanawat ’13, Ming Cai ‘12, and Ann Renninger (Swarthmore)
- University of Maryland NEXUS group
- Ken Heller (University of Minnesota)
- Tim McKay (University of Michigan)
- Mark Reeves (GWU)
- …. And many more!

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- 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.

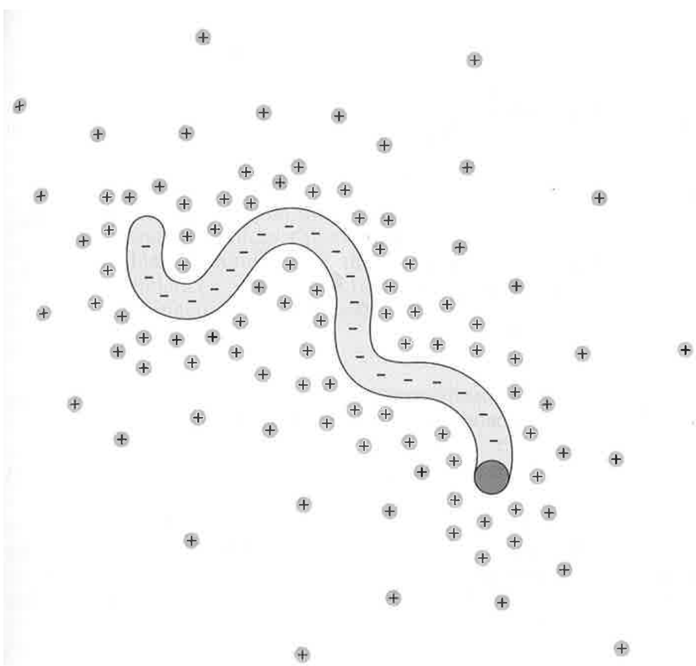

Figure 9.14 DNA in an ionic solution. The schematic shows the large negative charge density on the DNA molecule and the positive counterions in the surrounding solution.

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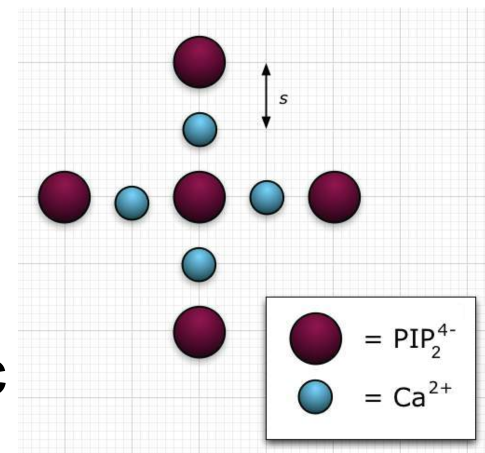
- Rare, highly negatively charged lipids need to cluster on the cell membrane surface for certain cellular processes. These clusters include small positive ions. Using the simple model of a cluster provided, show that the electric force on the bottom lipid is attractive with doubly charged Ca^{2+} ions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



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

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Motivate, select, and organize physics using “authentic” life science contexts

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

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

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Strategies

- 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

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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).*

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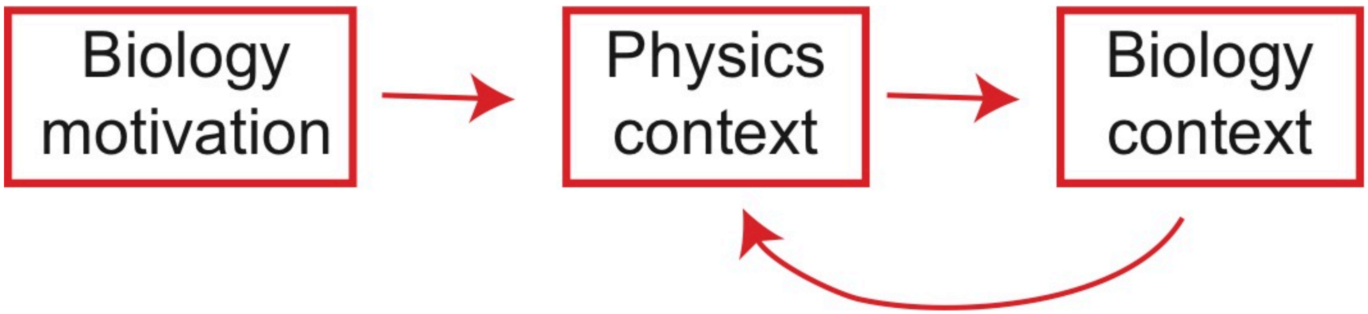
Implementation at Swarthmore

Physics in biological context



- Biology motivation and examples: chosen so that students feel physics gives real insight
- Both biology ("macro" and "micro") and instrumentation
- "Goldilocks" contexts are critical!
- Connect to other courses/student experiences

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Course material

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

Course material

- Modified syllabus
  - Expand electrostatics in media, circuits, optics
  - Omit Gauss's Law, AC circuits
  - Emphasize electric potential over field
  - Greatly reduce magnetism (focus on magnetic dipoles, omit field calculations)
  - Minimize induction (Faraday's Law, Lenz's Law)

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Course material

- Modified syllabus
- Organize each topic and unit around one or two biological contexts
  - Optics: confocal microscopy and human vision
  - Electricity/circuits: membrane potential and nerve signaling
  - Induction: Pacemaker safety

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Sound pedagogy

Utilize physics education knowledge base:

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

Adapt existing research-based materials whenever possible!

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

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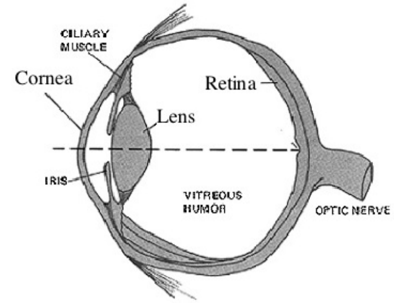
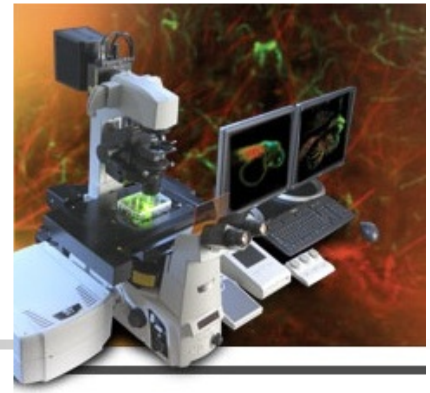
What does this look like?

Ray optics





- Usual physics approach:
  move object or lens with fixed *f*
  → moves image
- Human vision: fixed retina, adjustable lens
  (microscopes too)

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.

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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.

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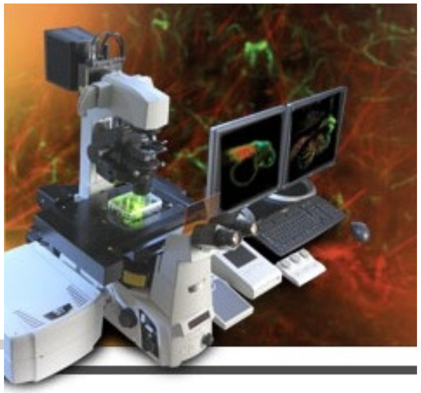
Microscopes



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

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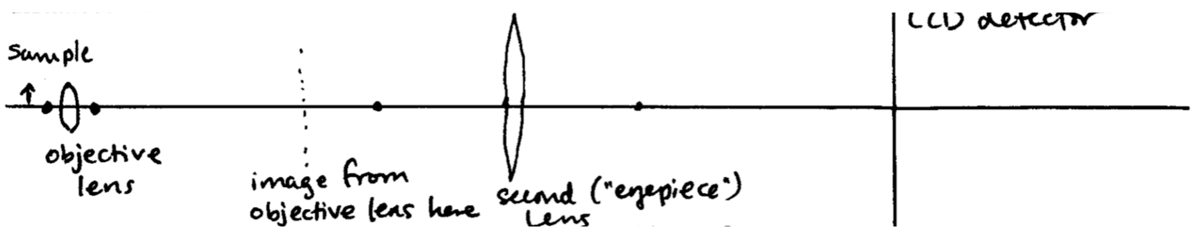
Biological context problem

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.

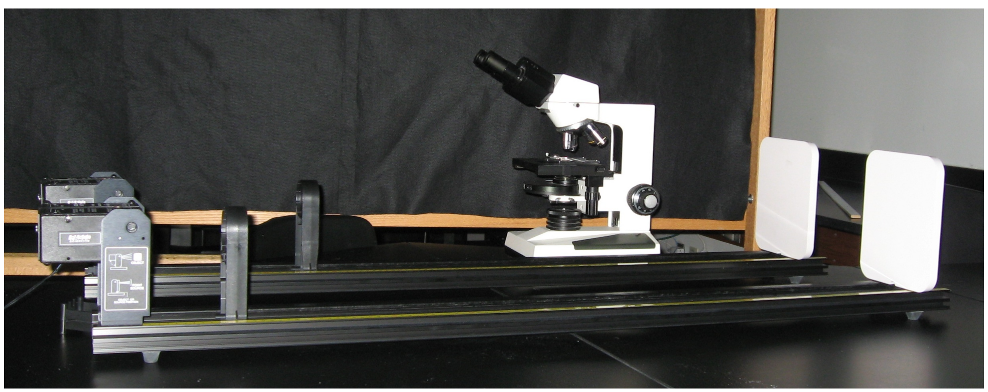


(a) Is the image on the detector real or virtual? Upright or inverted (relative to the sample)?

(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?

Labs: optical instruments

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



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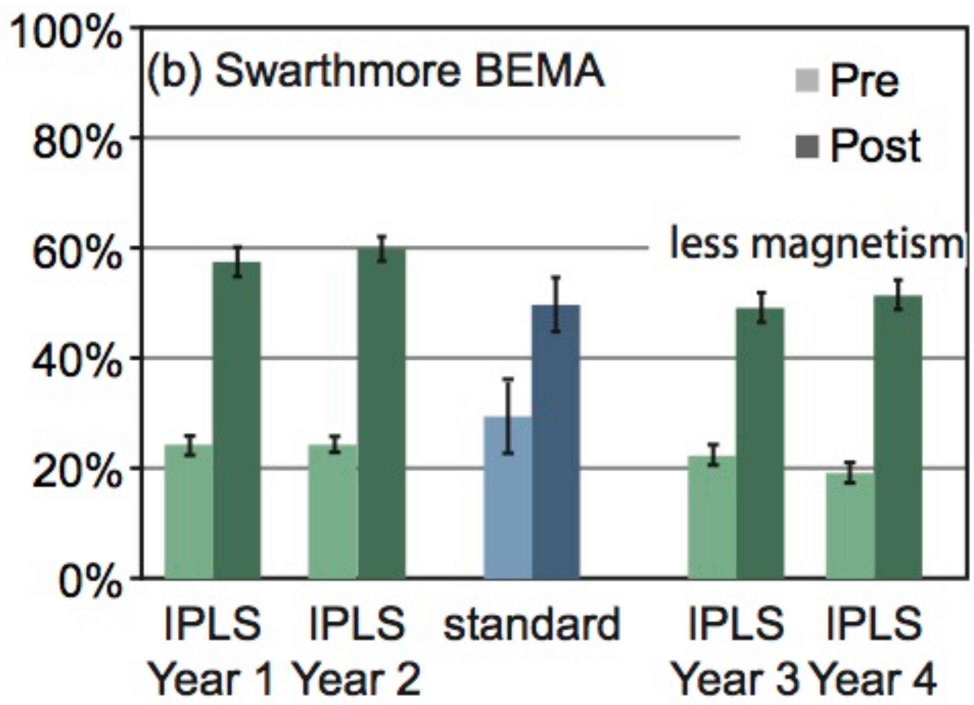
Does the course succeed?

Outcomes: BEMA



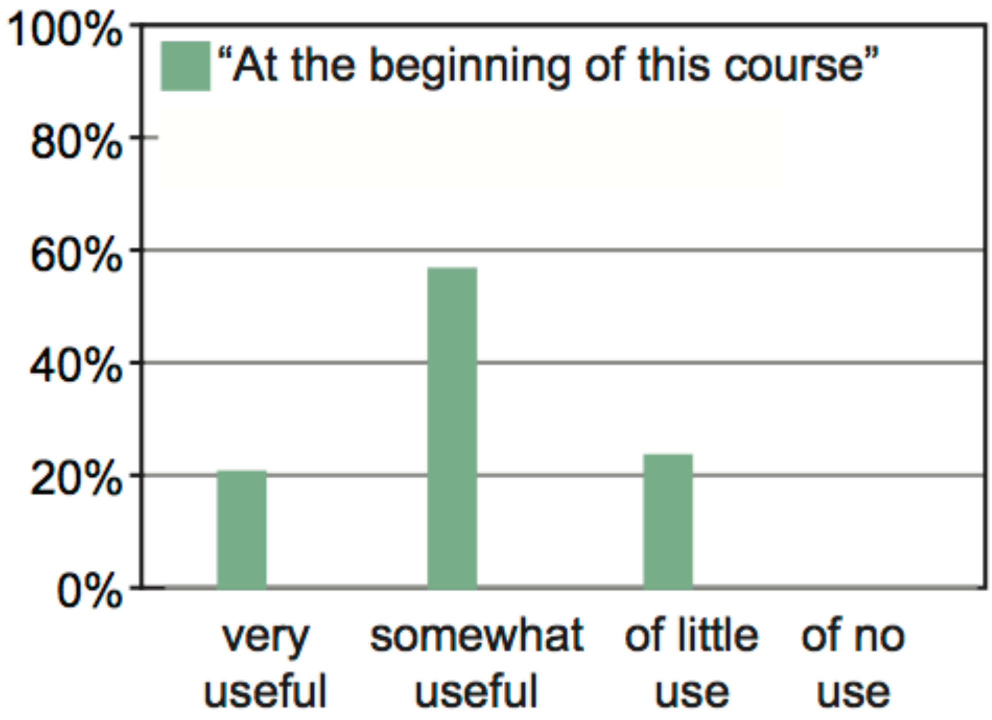
- Similar or better scores to traditional course
- Omit questions on transformer, induced E

Outcomes: student attitudes

- Very positive course evaluations
- High enrollment

2012 course evaluation (*N* = 68)

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



…. in understanding the life sciences.

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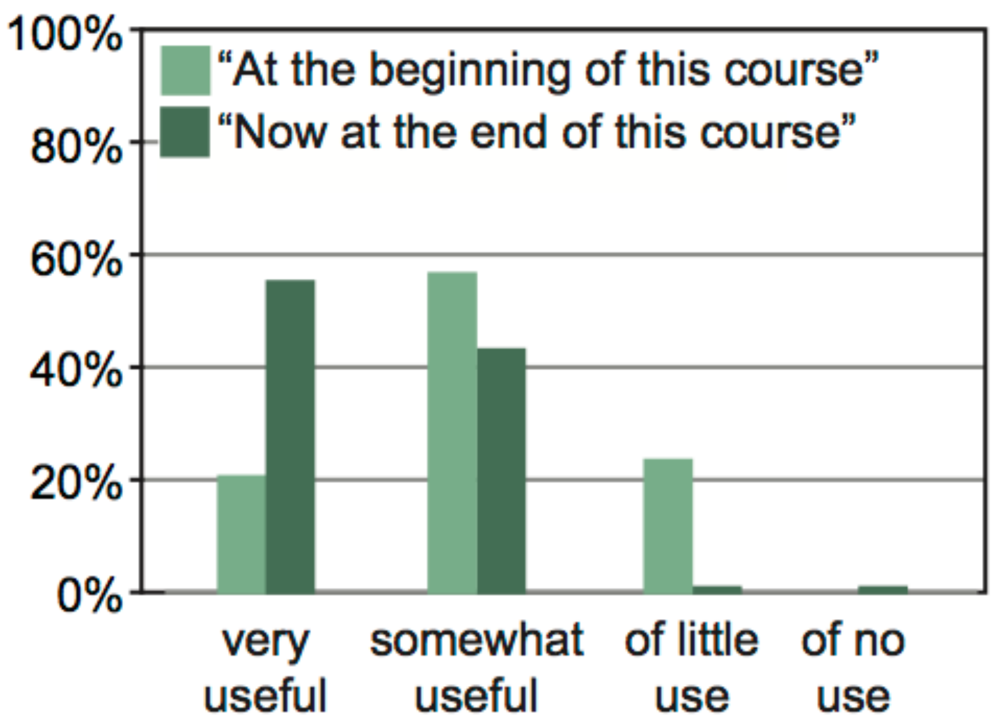
2012 course evaluation (*N* = 68)

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



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

…. in understanding the life sciences.

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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"

*Adams et al, PRST-PER **2**, 010101 (2006)*

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Outcomes: attitudes/beliefs

Statements probe attitudes to both content and learning process

"Learning physics changes my mind about how the world works."

"I study physics to learn knowledge that will be useful to me outside of school."

"In physics, mathematical formulas express meaningful relationships among measureable quantities."

"To learn physics, I only need to memorize solutions to sample problems."

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Outcomes: attitudes/beliefs

- Give survey (pre and post) in both standard first semester and IPLS second semester

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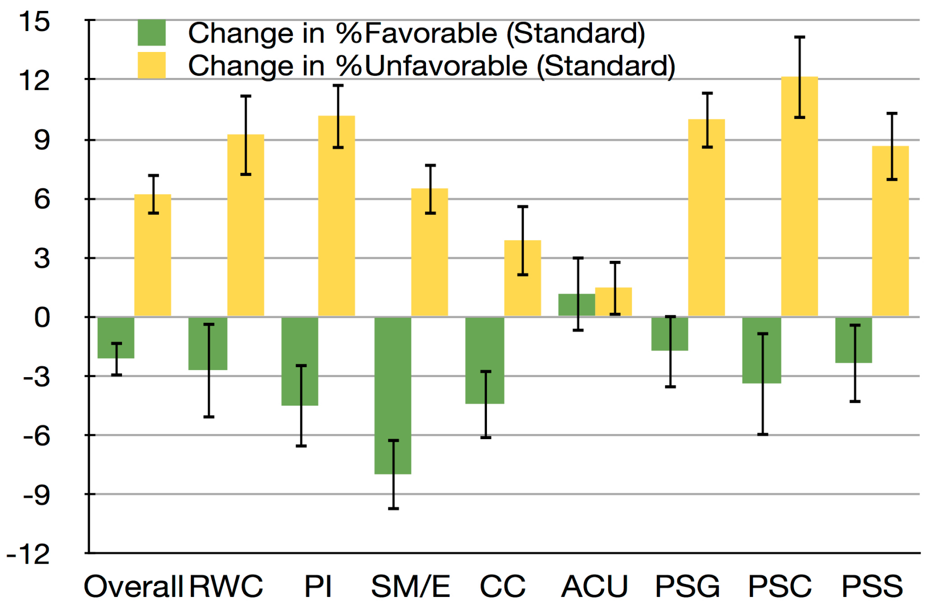
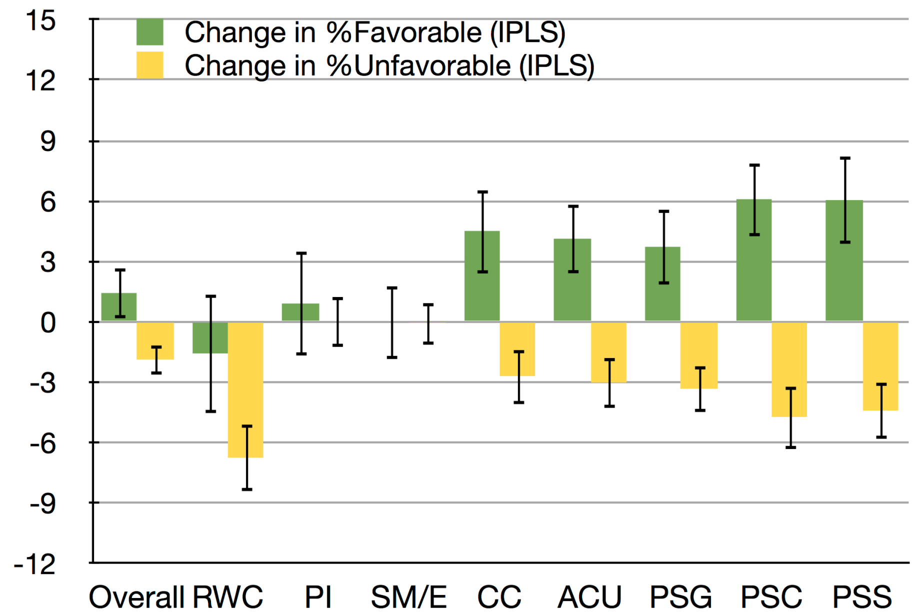
Changes in CLASS

Standard first semester



IPLS second semester



Attitudes decline in standard course (normal)
Hold steady/slightly improve in IPLS course

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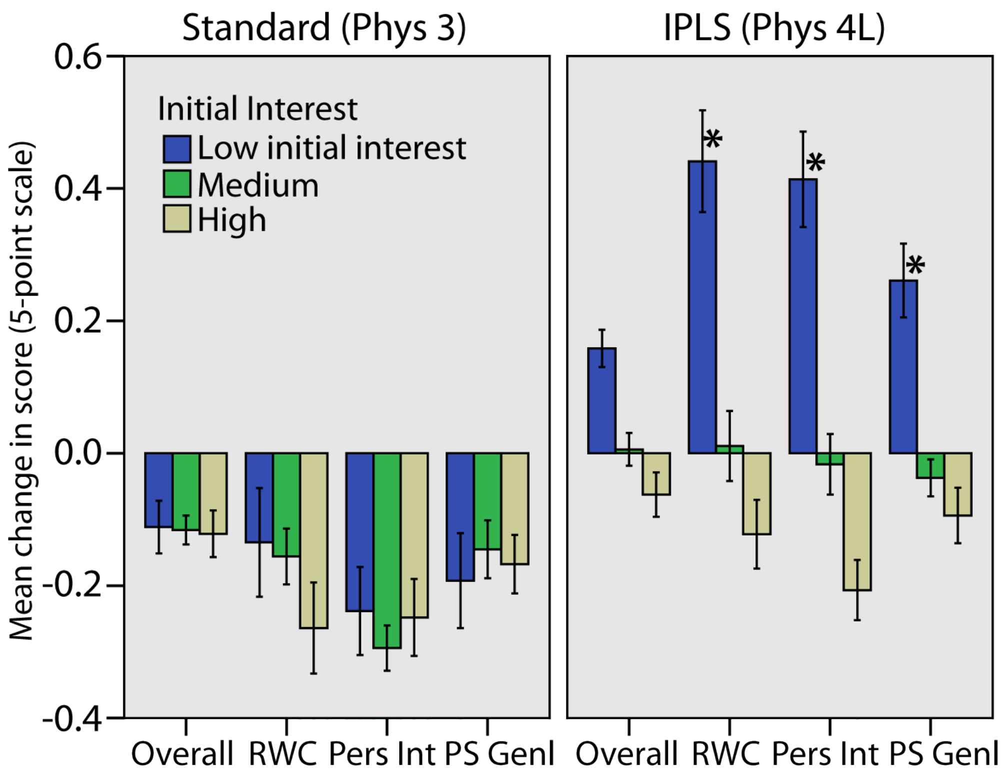
Prior interest metric

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

CLASS changes by initial interest



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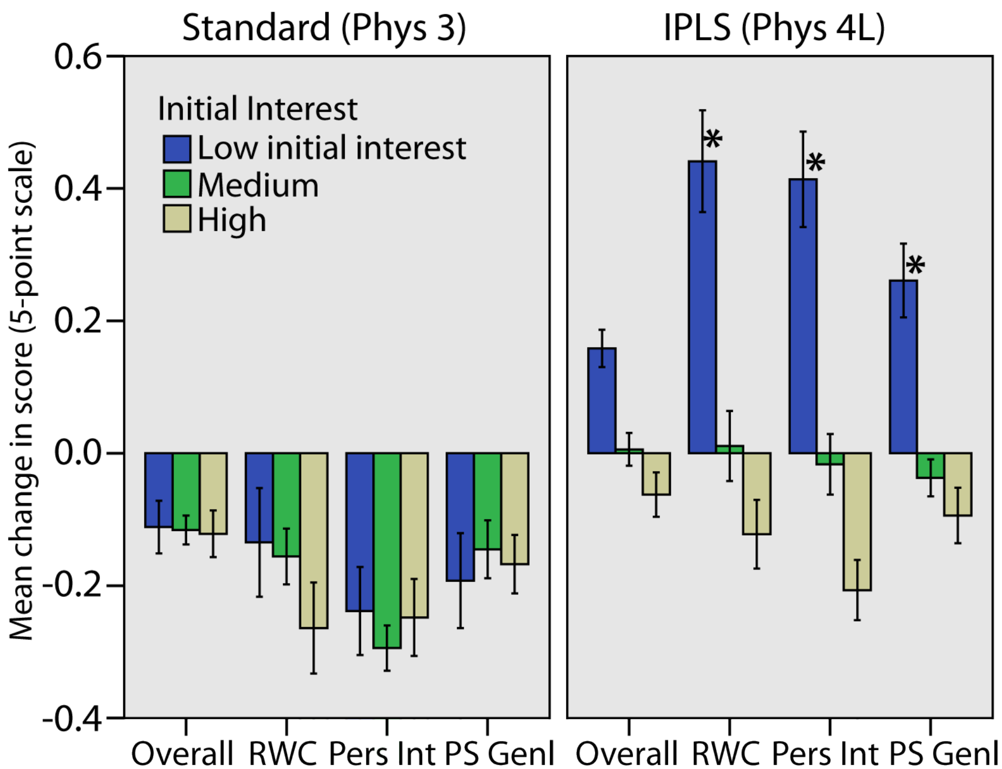
CLASS changes by initial interest



Students who come in with low interest gain significantly
Not clear if replicated, collecting more data this year

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Metric for example 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

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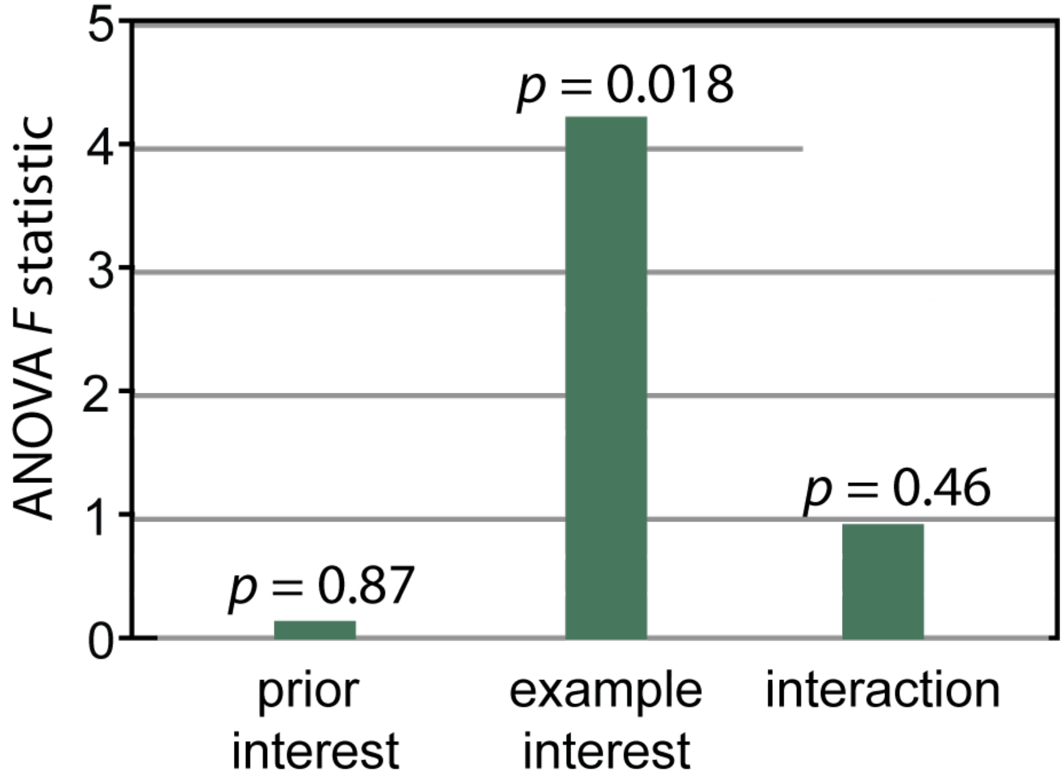
Interest in examples matters

Example interest, more than prior interest, predicts exam scores



$$F = \frac{\text{explained variance}}{\text{unexplained variance}}$$

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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)

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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)

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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

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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

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