# Optimizing Introductory Physics for the Life Sciences

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HHMI

NSF

# Today's talk

- Design of introductory physics course for life science students (IPLS)
- Evidence for effectiveness:

  student learning

  student interest in and value of physics
- Process for course optimization
- Specifics from Swarthmore

What are the most important goals for a physics course for life science and premedical students?

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Prepare and motivate
life science students to use
physics tools
in their future work

"Connections between biology and the other scientific disciplines need to be developed and reinforced so that interdisciplinary thinking and work become second nature."

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For students to believe such connections:

course needs a suitable “frame”

# What does a frame do?

- Provides structure (building frame)
- Focuses attention and supports (picture frame)

For this course, provides motivation and context

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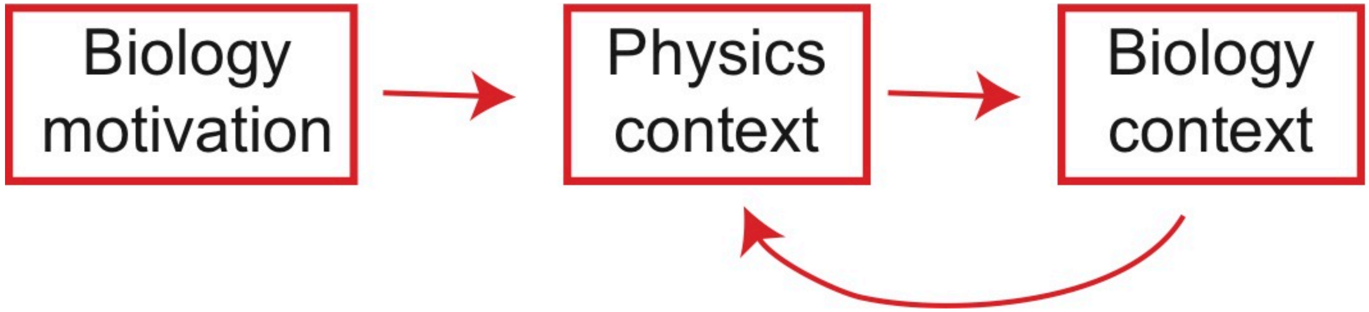
Show AND tell students:

course material is chosen to support your long-term goals

you should be connecting physics to the other science you know

# Physics in biological context

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# IPLS course optimization

- Select most important physics content (while keeping physics story line)

*BIO 2010,* NRC (2003)

*Scientific Foundations for Future Physicians* (2009), HHMI/AAMC

*Vision & Change*, AAAS (2011)

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# IPLS course optimization

Organize each topic and unit around one or two biological contexts

- Optics: animal vision and microscopy
- Waves: echolocation
- Electricity/circuits: cell membrane potential, nerve signaling
- Magnetism and induction: magnetic sensing, NMR

  (induction stays in for "cultural" reasons)

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# IPLS course optimization

- Most important physics content
- Develop “physics toolkit”: modeling, rigorous qualitative reasoning, quantitative skills, data

# IPLS course optimization

- Most relevant physics content
- “Physics toolkit”
- Use research-validated pedagogy

SWARTHMORE

# IPLS course optimization

- Most relevant physics content
- "Physics toolkit"
- Research-validated pedagogy
- Give students opportunities to apply physics meaningfully to the life sciences

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"authentic" life science problems

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

- 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.

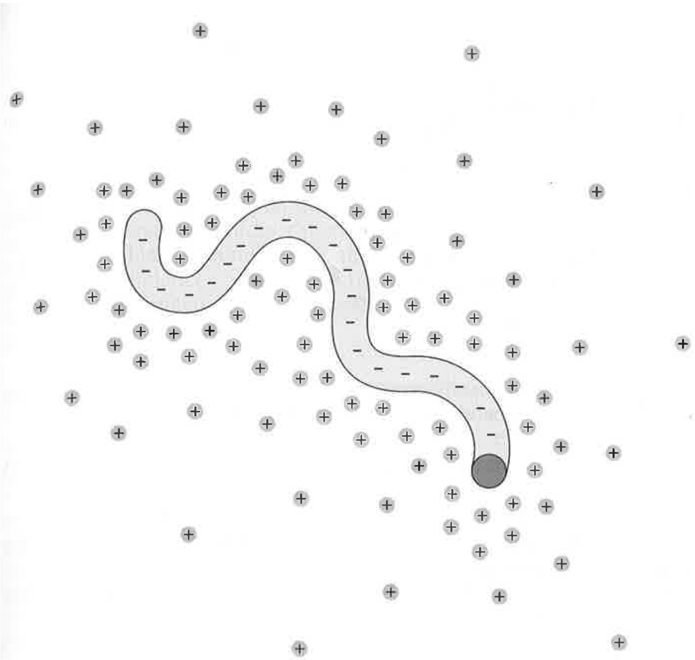

**Figure 9.14** DNA in an ionic solution. The schematic shows the large negative charge density on the DNA molecule and the positive counterions in the surrounding solution.

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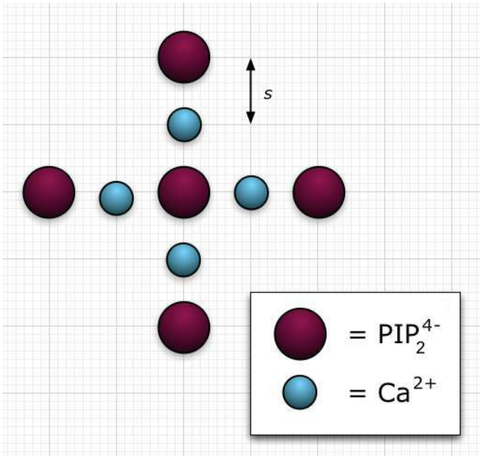
- Rare, highly negatively charged lipids form clusters on the cell membrane surface for certain cellular processes. These clusters include small positive ions.
For the simple model of a cluster shown, show that with doubly charged $Ca^{2+}$ ions, electric forces hold the cluster together — but not with singly charged Na+ ions.




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

SWARTHMORE

*Your questions:*

“Is there evidence that [such a course]:

- improves physics understanding?
- improves life science understanding?
- improves student interest?”

“How do we know that something needs to be fixed?”

# Research colleagues

- Panchompoo (Fai) Wisittanawat ’13
- Ming Cai ‘12
- K. Ann Renninger (Educational Studies)
- Benjamin Geller ‘01 (PhD 2014, UMD)

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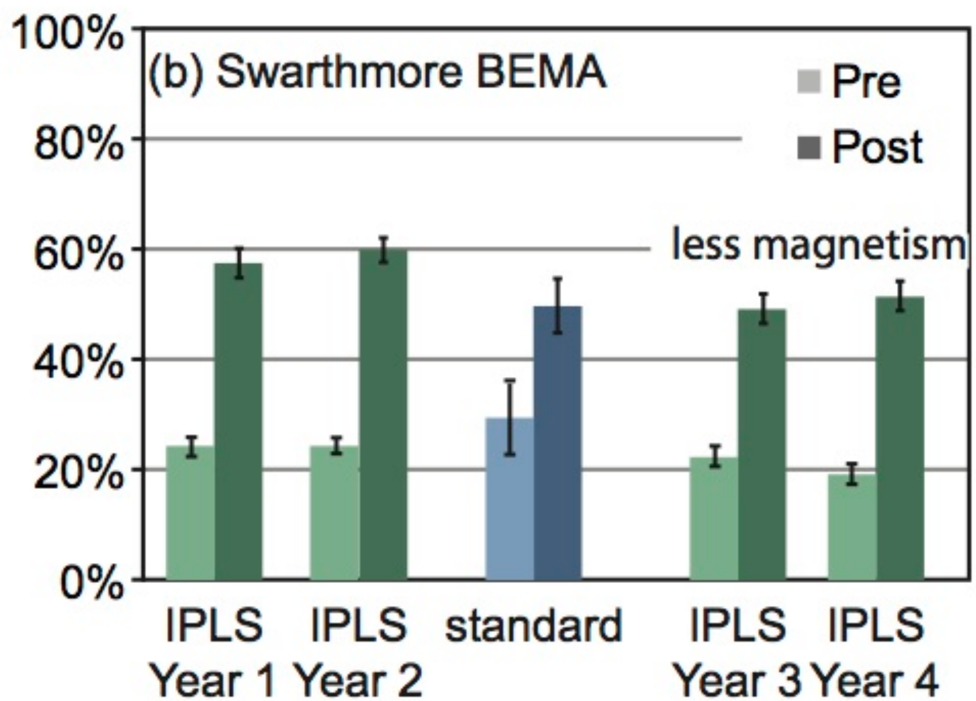
# Physics understanding: E&M




*Crouch and Heller,* Am. J. Phys. **82**, *378 (2014).*

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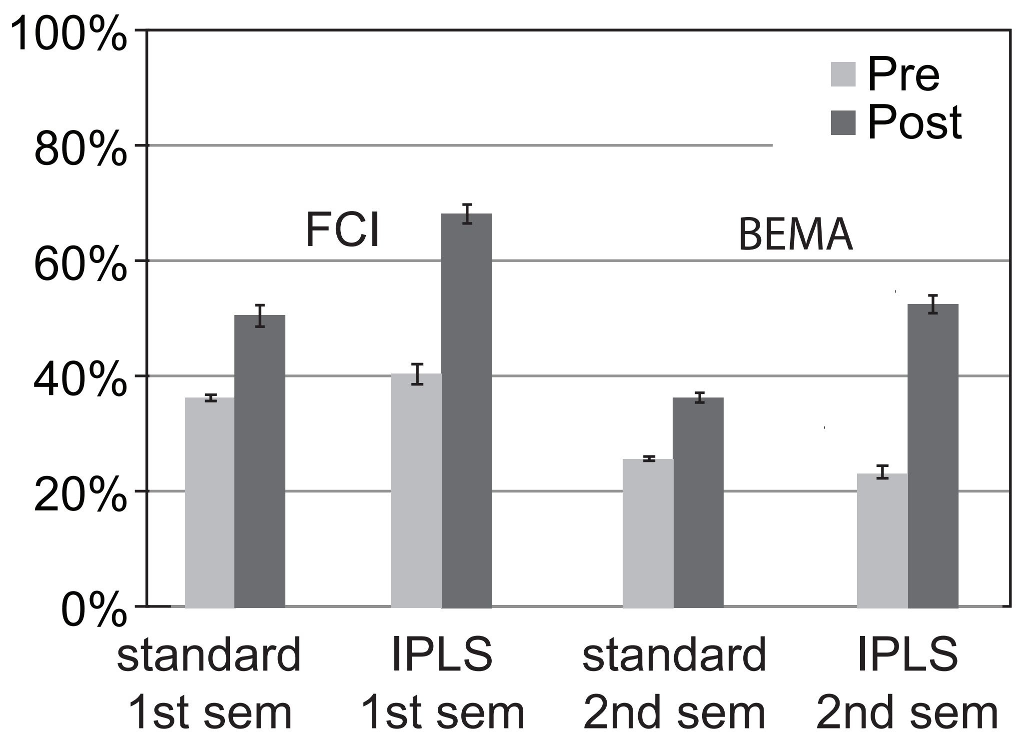
# Physics understanding: UMN




*Crouch and Heller,* Am. J. Phys. **82**, *378 (2014).*

SWARTHMORE

*Your questions:*

“Is there evidence that [such a course]:

- improves physics understanding?
- improves life science understanding?
- improves student interest?”

Longitudinal study needed!

# Unsolicited email from student

- "I wanted to tell you how well Physics 4L prepared me for my summer research …. 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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*Your questions:*

"Is there evidence that [such a course]:

- improves physics understanding?
- improves life science understanding?
- improves student interest?"

# Student interest and attitudes

Do students:

- Find physics useful for the life sciences?
- Understand how to learn and use physics?
- Develop and benefit from interest in physics?

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# Outcomes: attitudes

Do students:

- Find physics useful for the life sciences?
- Understand how to learn and use physics?
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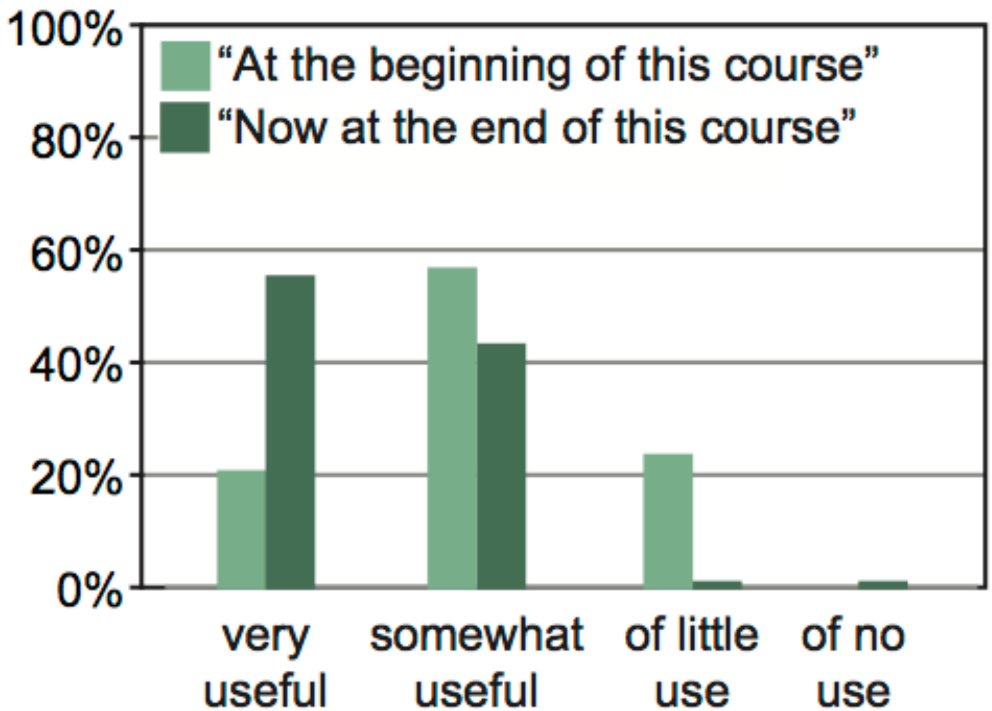
# 2012 course evaluation (*N* = 68)

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




*Replicated in 2013 and 2014 (zero "of no use" responses)*

…. in understanding the life sciences.

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# Outcomes: attitudes

Do students:

- Find physics useful for the life sciences?
- Understand how to learn and use physics?
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# Outcomes: attitudes

- 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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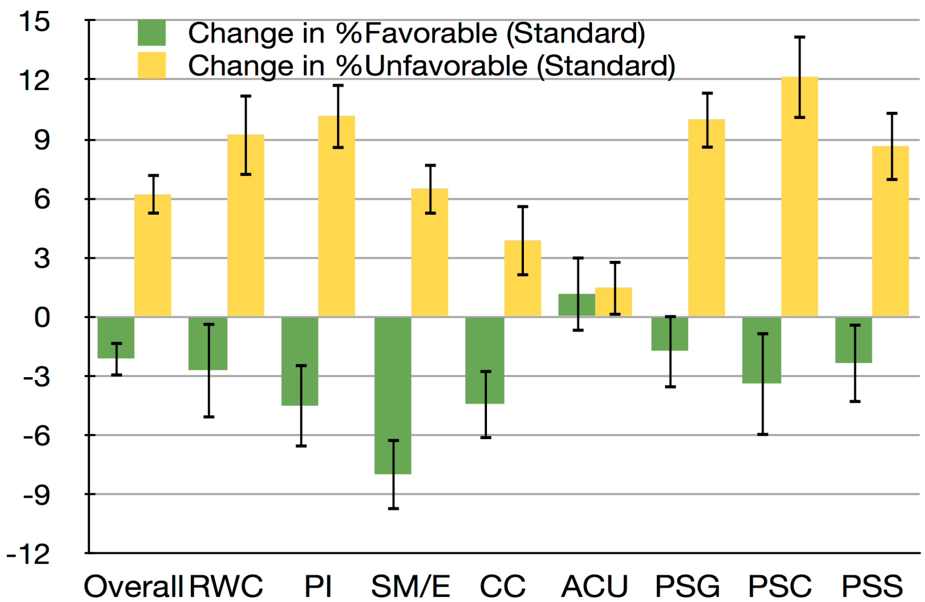
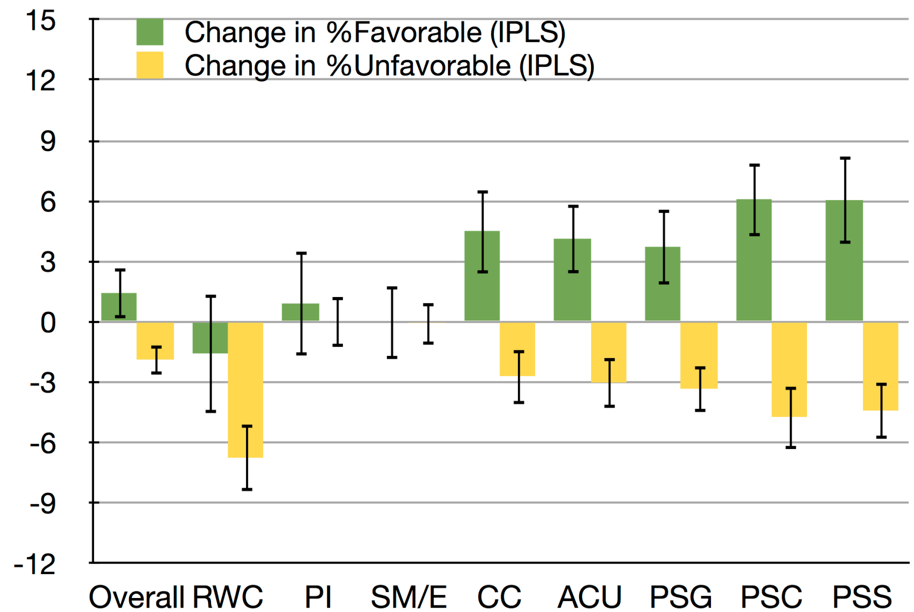
# Changes in CLASS

Standard first semester




IPLS second semester




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

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# Outcomes: attitudes

Do students:

- Find physics useful for the life sciences?
- Understand how to learn and use physics?
- Develop and benefit from interest in physics?

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Compared to teaching the same physics without the life science examples, by including these examples, Physics 4L was:

| | |
|---|---|
| Much more interesting to me | 64% |
| Somewhat more interesting to me | 24% |
| Equally interesting to me | 12% |

…. in understanding the life sciences.

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# Prior interest in physics

- Used set of 12 CLASS pre-survey items as a metric for students' initial interest in physics
- Categorized students into low/medium/high prior interest

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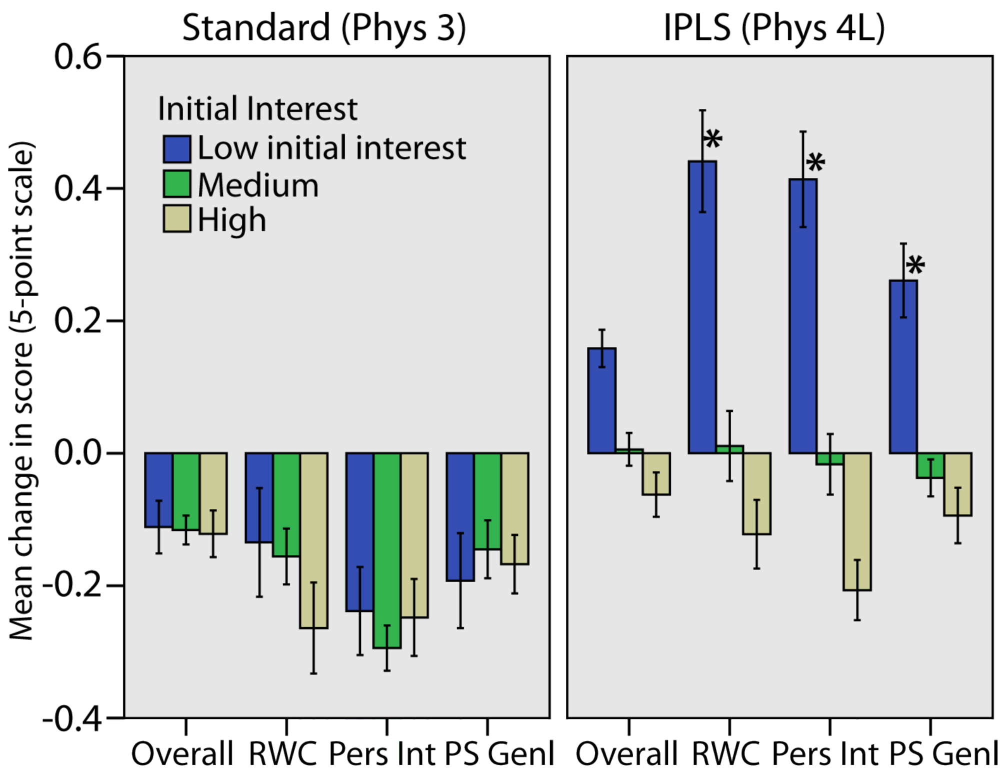
# CLASS changes by prior interest




Students who start with low interest gain significantly
Not replicated in 2013, but replicated in 2014

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# Example interest metric

- Students rated their interest in each of 8 biological examples at end of semester
- Example interest = average rating

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# Interest in examples matters

Example interest, more than prior interest, predicts exam scores for 2012 and 13 data

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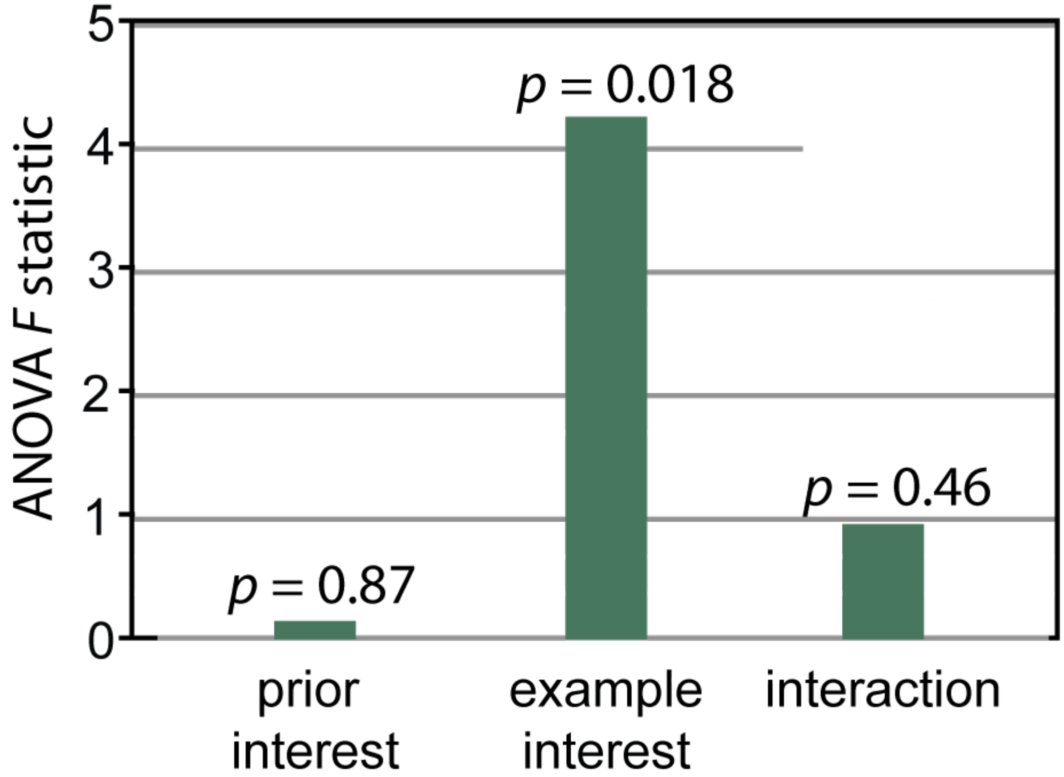
# Interest in examples matters

Variance in composite exam scores for each student, 2012 & 13




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

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# How was the Swarthmore redesign carried out?

# Choosing content

- Consulted with biology, biochemistry, and medical faculty to develop syllabus:
  - What are students learning in their courses and using in research?
  - What is important for students to know?
- Identified contexts that connect to local curriculum and are pedagogically tractable
- Embed physics instruction into this frame (adapt research-based materials whenever possible!)

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# Sound pedagogy

Utilize physics education knowledge base:

- Align stated expectations with tests (and HW)
- Emphasize (and test!!) connecting qualitative reasoning and quantitative problem solving
- Peer Instruction lecture
- Weekly problem-solving laboratory
- Optional group problem solving sessions for challenging problems

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

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How might you redesign your own course?

# Redesigning

- Consult with your own biology/biochemistry faculty to identify local needs and opportunities
- Use shared materials!

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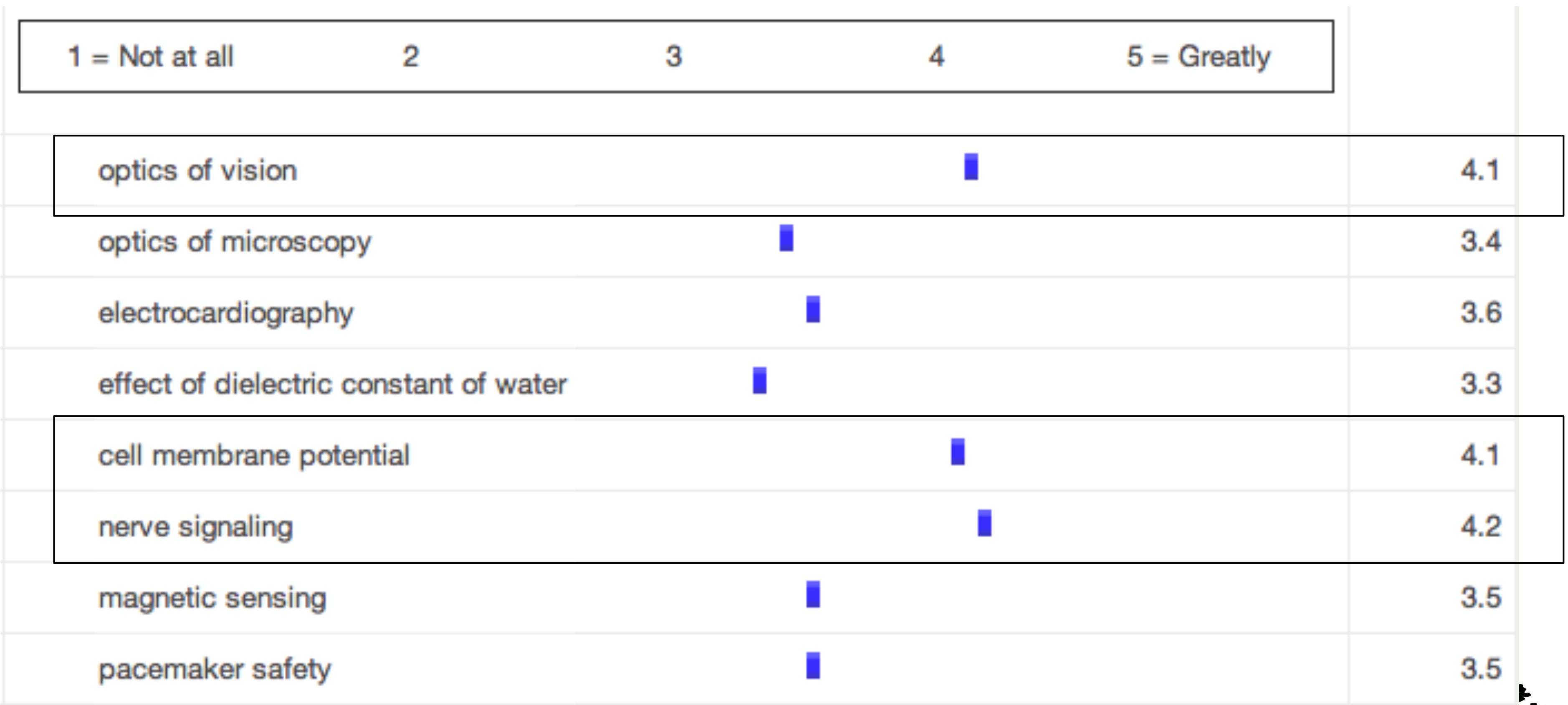
# Resources available

- IPLS syllabi and materials on Compadre (AIP): www.compadre.org
- materials.physics.swarthmore.edu/IPLSMaterials
- Books:
  - I currently use Knight (calc-based)
  - NEXUS wiki-book
  - Tim McKay and I are working on a textbook
  - Sternheim & Kane (calc-based)

Students are interested in learning more about things they already consider important

## Which of the following sparked your interest, and how much?




*N* = 66, SE = 0.1 for all rankings

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“Knowing about the biological phenomena involved helped me better appreciate [the physics]. For example, … I loved the HW problem asking us to calculate the electric forces between DNA molecules in pure water…. We found that the electric forces should be too great for so much DNA to be packed together in the nucleus. This was a turning point for me, as I had never considered this before, but now that I had, it seemed to be a very significant problem. If I hadn’t known anything about DNA, this would not have been as worthwhile of a problem.”

- ”

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# IPLS at Swarthmore

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# IPLS at Swarthmore

- Before 2008, taught both engineers and life science students in a single calculus-based, 2-semester physics sequence
- Since 2008:
  - All students take common 1st semester
  - Both standard and IPLS 2nd semester courses offered: waves, optics, E&M
- IPLS 1st semester to be launched Fall 2015

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# Course reform collaborators

- University of Maryland NEXUS group
- Ken Heller (Univ of Minnesota)
- Tim McKay (Univ of Michigan)
- Mark Reeves (George Washington Univ)
- Logan McCarty (Harvard University) …

…. And many more!

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# Additions to 2nd semester

- More geometric and wave optics
- Electrostatics in media
- More circuits (neural circuit models, electrophysiology)
- Emphasize electric potential more than field
- Focus magnetism on interactions of dipoles with fields

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# Reductions in 2nd semester

- Omit Gauss's Law
- Omit magnetic field calculations
- Only do simple cases of induction
- Omit AC circuits and inductance
- Omit Maxwell's equations

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# Planned additions to 1st semester

- Energy: open systems, microscopic
- Fluid statics and dynamics
- Statistical physics: diffusion, osmotic pressure, electrochemistry, free energy

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# Planned omissions (1st semester)

- Significantly reduce kinematics
- Minimize 2D/3D treatment of momentum, collisions
- Minimize angular momentum
- Omit angular acceleration/kinematics
- Omit celestial mechanics, relativity

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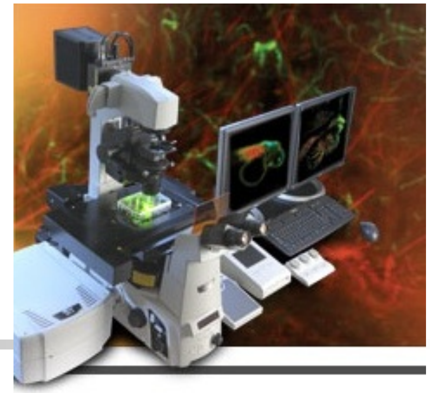
# Case study: Geometric optics

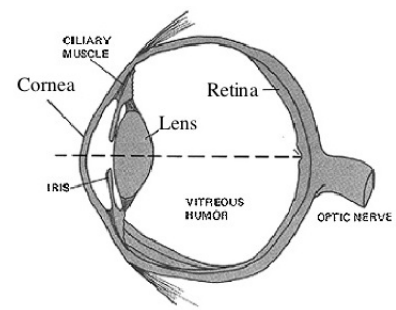
# Images with lenses



- Usual physics approach:

  move object or lens with fixed *f*

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

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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 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.

# 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:
  - single microscope design
  - formula-driven
- Instead:
  - Connect familiar ideas (magnification) to new physics ideas (focal length, object and image distance, real/virtual image)
  - Teach students to analyze images formed with multiple lenses

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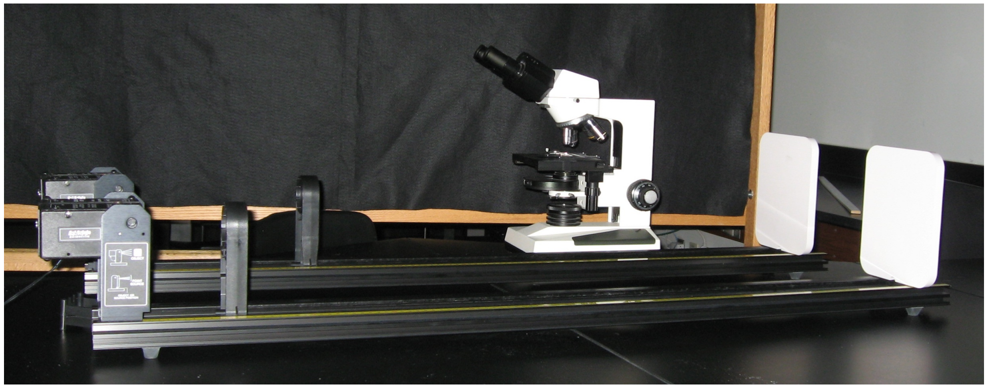
# Lab: optical instruments

- Relate magnification to *f* for different lenses all subject to fixed ($s_o + s_i$)
- Design and construct two different types of two-lens microscope:

    final image recorded on “camera”

    final image viewed by eye



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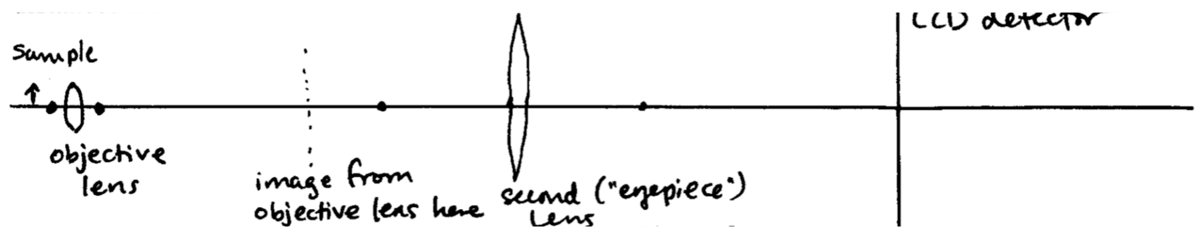
# Quantitative problem

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?

# Summary

- IPLS class is rebuilt around authentic biological contexts
- The biggest change is the “frame”
- Assessment:

  Comparable conceptual learning to standard course

  Substantially improved interest and other perceptions of physics

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# Thanks to …


- HHMI and Mellon grants to Swarthmore
- NSF TUES (DUE-1122941)
- Ann Renninger, Fai Wisittanawat ’13, Ming Cai ’12, and Ben Geller ‘01
- Ann Ruether
- Colleagues at Swarthmore and elsewhere
- University of Maryland NEXUS group


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