Optimizing Introductory Physics for the Life Sciences

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Swarthmore College
9 June 2014

Three take-home messages

- Reformed IPLS course:
  choose and organize course material so that students experience the value of physics for the life sciences
- Such reforms can be modest
- To succeed, find out what your students do in their home departments

SWARTHMORE

Select, organize, and motivate physics using "authentic" life science contexts

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.

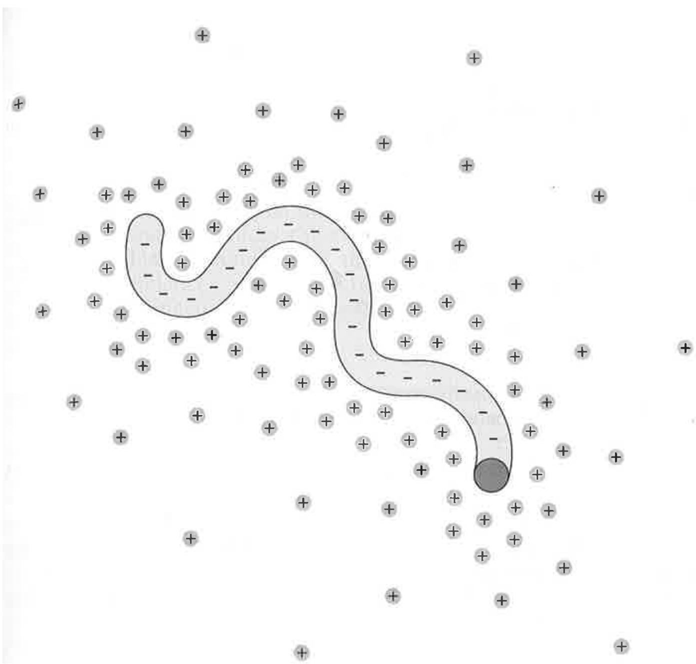
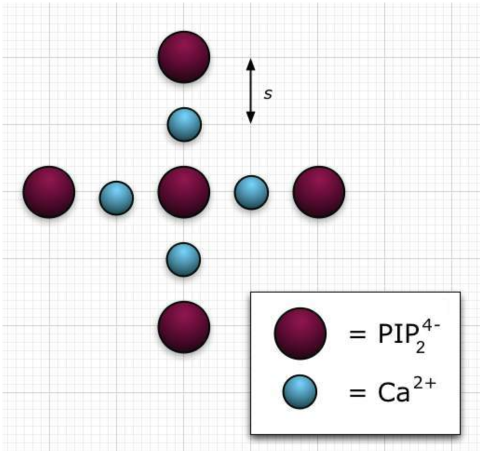


Figure 9.14 DNA in an ionic solution. The schematic shows the large negative charge density on the DNA molecule and the positive counterions in the surrounding solution.

- 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.



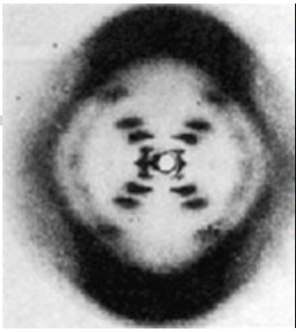
Based on work by Wang, Collins, Guo, Smith-Dupont, Gai, Svitkina, and Janmey, 2011.

SWARTHMORE

IPLS course reform

- Focus on most important physics content
- Develop physics toolkit: modeling, rigorous qualitative reasoning, quantitative skills, data

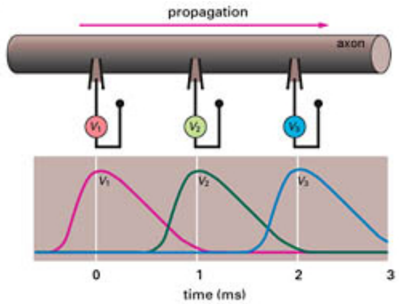
Calls for reform



BIO 2010, NRC (2003)

Vision & Change, AAAS (2011)

- Importance of physical science and quantitative methods for future life scientists
- "Connections between biology and the other scientific disciplines need to be developed and reinforced so that interdisciplinary thinking and work become second nature."



SWARTHMORE

Calls for reform

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

- Recommends competency-based (*not* course-based) admissions requirements
- Competencies include both physics content and scientific skills
- New MCAT to be introduced in 2015

AAMC
Tomorrow's Doctors, Tomorrow's Cures®

SWARTHMORE

IPLS course reform

- Focus on most important physics content
- Develop physics toolkit: modeling, rigorous qualitative reasoning, quantitative skills, data
- Prepare and motivate students to apply physics tools in their future work

SWARTHMORE

Deliberately cultivate student interest and perception of utility of physics

Explicit messages to students:

- course material is chosen to support your long-term goals
- you should be connecting physics to the other science you know

Why are interest and utility so important?

Interest

- Interest facilitates learning (effort, persistence)
- “Situational” interest (triggered by course) shown to predict:
  - performance
  - continued interest
  - future engagement with material

Renninger and Hidi, Ed. Psych. **4**, *111 (2006).*

SWARTHMORE

Relevance and interest

9th grade science students assigned to reflect on relevance of course material

for students with low initial expectations of success, both course grades and self-reported interest increased

Hulleman and Haraciewicz, Science **326***, 1410 (2009).*

Expansive framing

- HS students tutored about circulatory system
- Two different "framings":
  - Restricted to the class
  - Broadly relevant and applicable
- In later lesson on respiratory system, students receiving broadly relevant ("expansive") framing applied previous lesson more successfully

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

SWARTHMORE

IPLS at Swarthmore

SWARTHMORE

IPLS at Swarthmore

- All students take standard 1st semester of university physics
- Both standard and IPLS 2nd semester courses offered since 2008: waves, optics, E&M
- IPLS 1st semester to be launched in Fall 2015

SWARTHMORE

Additions to 2nd semester

- More geometric and wave optics
- Electrostatics in media
- More circuits (neural circuit models, electrophysiology)
- Emphasize electric potential over field

Reductions in 2nd semester

- Omit Gauss's Law
- Streamline magnetism (focus on dipoles, omit field calculations)
- Simple cases of induction
- Omit AC circuits and inductance
- Omit Maxwell's equations

Planned additions to 1st semester

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

SWARTHMORE

Planned omissions (1st semester)

- Significantly reduce kinematics
- 2D/3D momentum and collisions
- Angular dynamics
- Planetary orbits, universal gravitation

SWARTHMORE

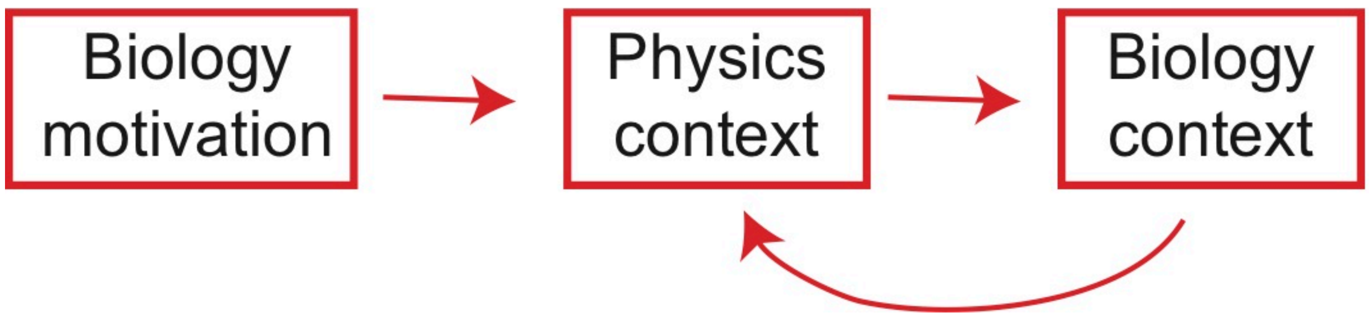
Course design

Organize each topic and unit around one or two biological contexts

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

SWARTHMORE

Physics in biological context



SWARTHMORE

Sound pedagogy

Utilize physics education knowledge base:

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

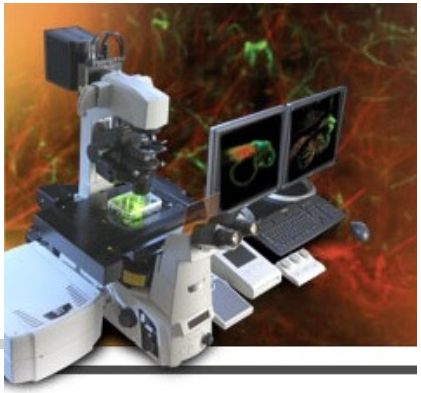
Adapt existing research-based materials whenever possible!

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

SWARTHMORE

Case study: Geometric optics

Images with lenses

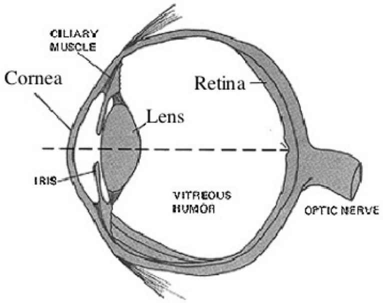


- Usual physics approach:

  move object or lens with fixed *f*

  → moves image

- Human vision: fixed retina, adjustable lens



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.

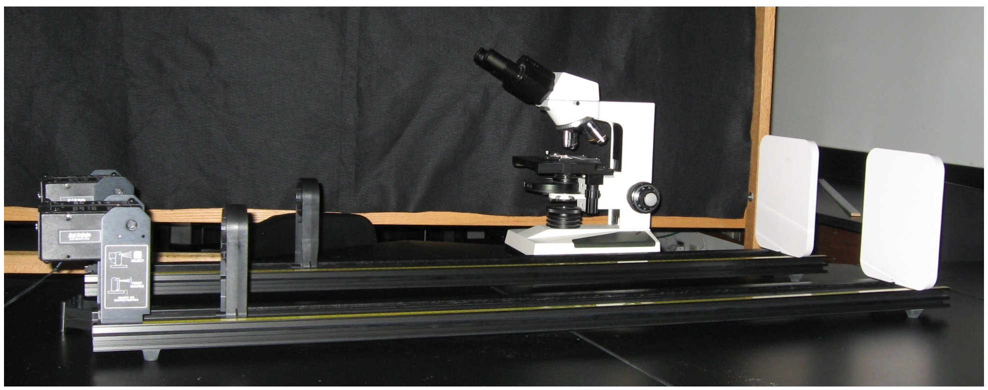
SWARTHMORE

Microscopes

- Usual physics textbooks:
  - 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

Labs: optical instruments

- Relate magnification to *f* for different lenses all subject to fixed ($s_o + s_i$)

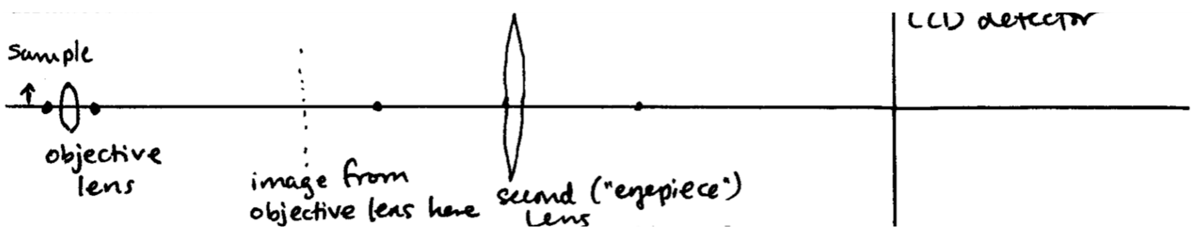


- Construct a two-lens microscope to produce final image that is either real (recorded on “camera”) or virtual (viewed by eye)

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

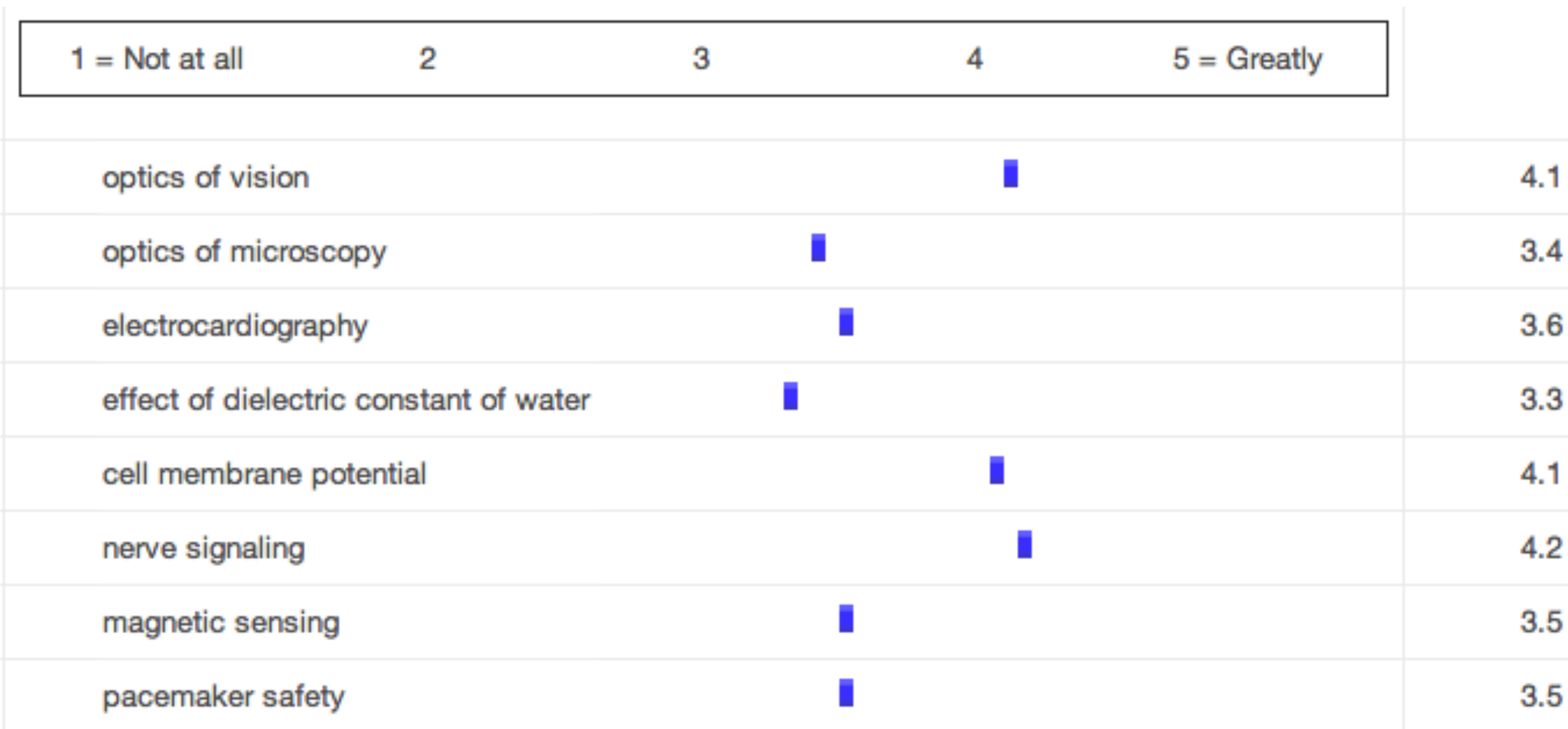
Choosing contexts

- Authentic but pedagogically tractable (follow PER approaches when possible)
- Consult colleagues and literature
- Know what’s in the biology and chemistry curriculum!

SWARTHMORE

2012 student interest in contexts

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



N = 66, SE = 0.1 for all rankings

SWARTHMORE

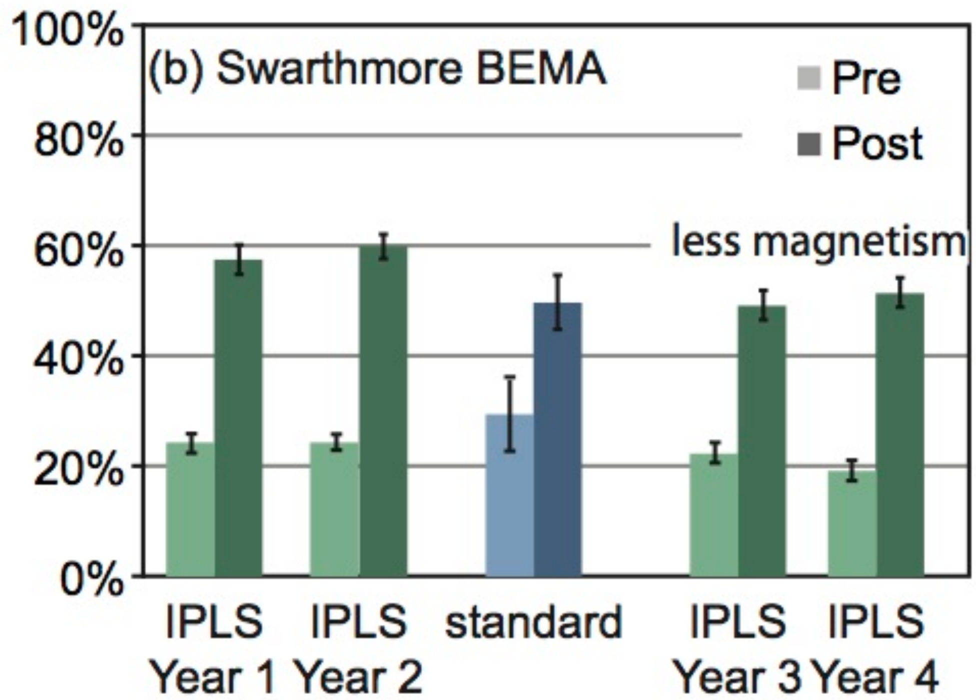
What are the outcomes?

Research colleagues

- Panchompoo (Fai) Wisittanawat ’13
- Ming Cai ‘12
- K. Ann Renninger (Educational Studies)
- University of Maryland NEXUS
- Kenneth Heller, University of MN

SWARTHMORE

Content learning: BEMA



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

Outcomes: student attitudes

- Do students appreciate the usefulness of physics for the life sciences?
- Does their understanding of how physics works become more expert-like?
- Does the course engage their interest, and does that matter?

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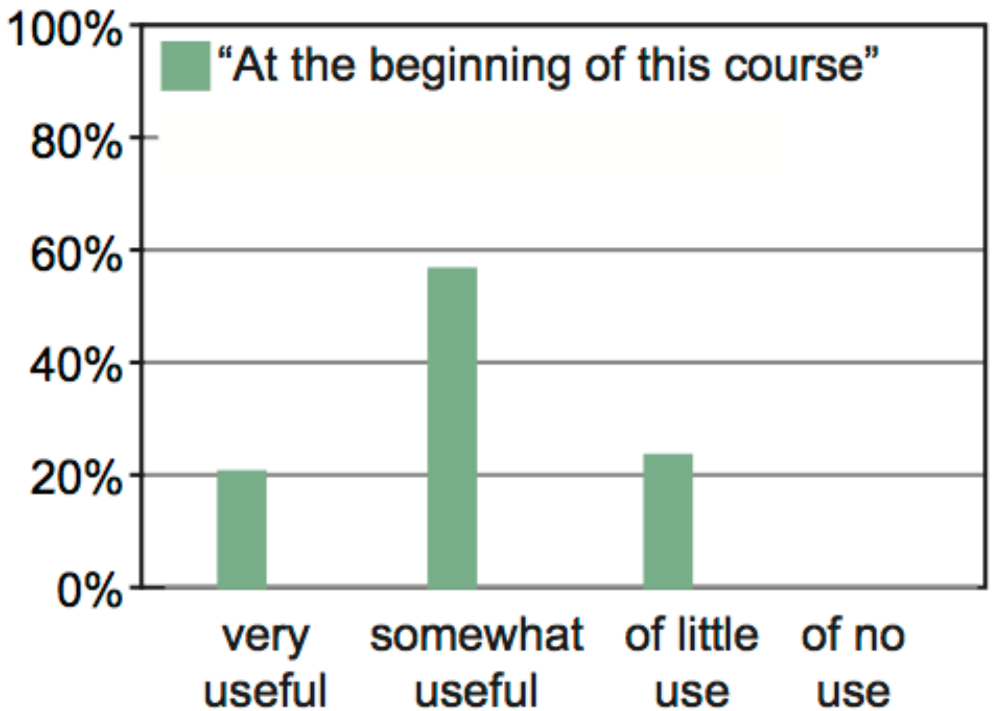
SWARTHMORE

2012 course evaluation (N = 68)

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



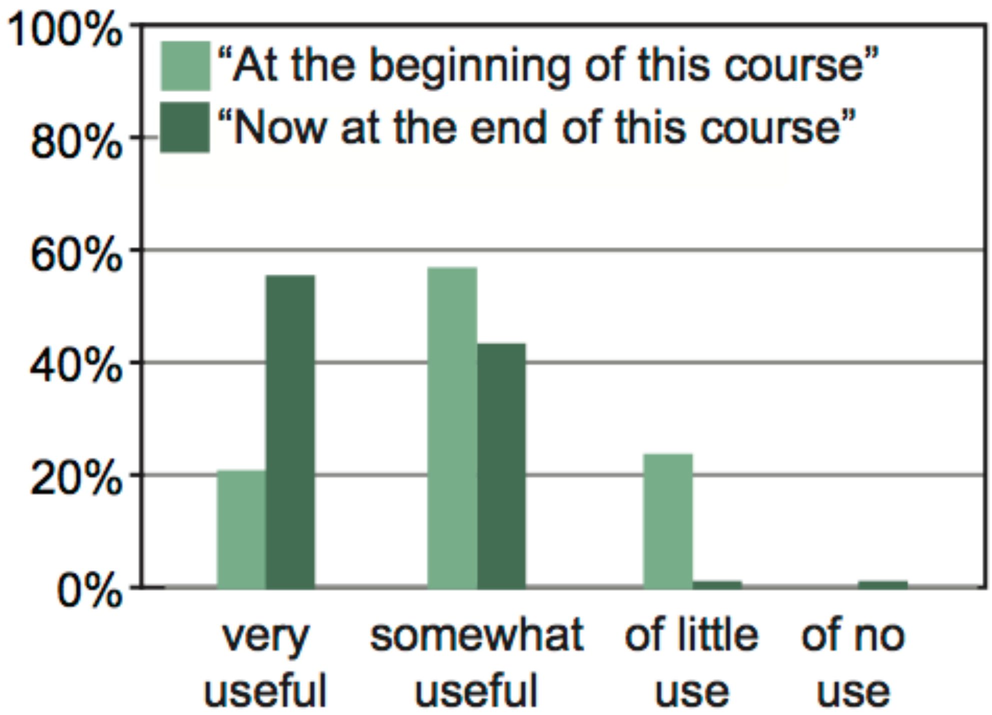
Question from UMD PERG

…. in understanding the life sciences.

SWARTHMORE

2012 course evaluation (*N* = 68)

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



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SWARTHMORE

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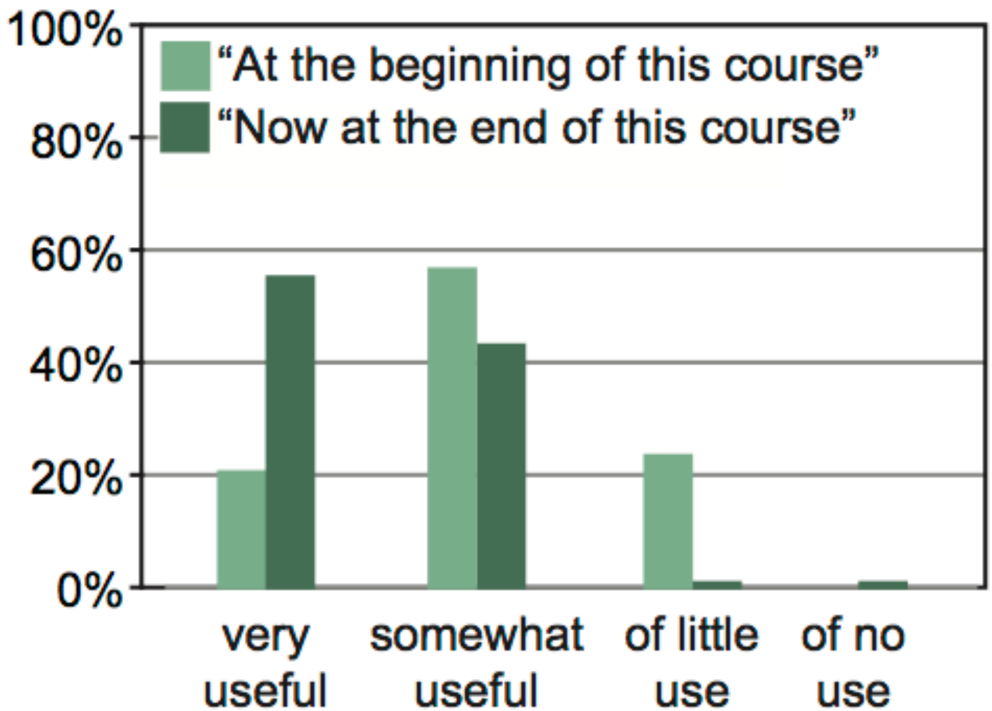

Replicated in 2013 and 2014 (zero “of no use” responses)

…. in understanding the life sciences.

SWARTHMORE

Outcomes: student attitudes

- Do students appreciate the usefulness of physics for the life sciences?
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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”

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

SWARTHMORE

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.”

SWARTHMORE

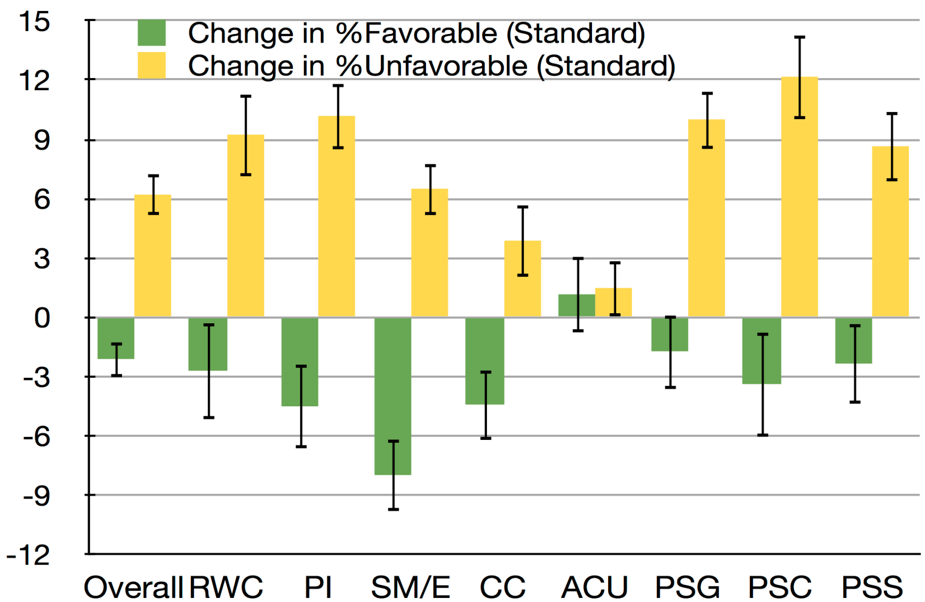
Outcomes: attitudes/beliefs

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

SWARTHMORE

Changes in CLASS

Standard first semester

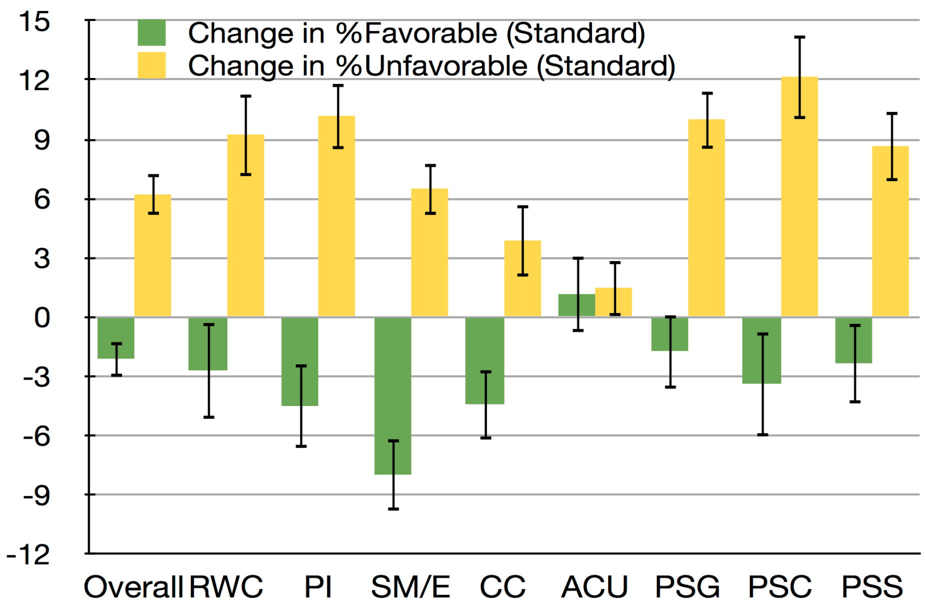


Attitudes decline in standard course (normal)

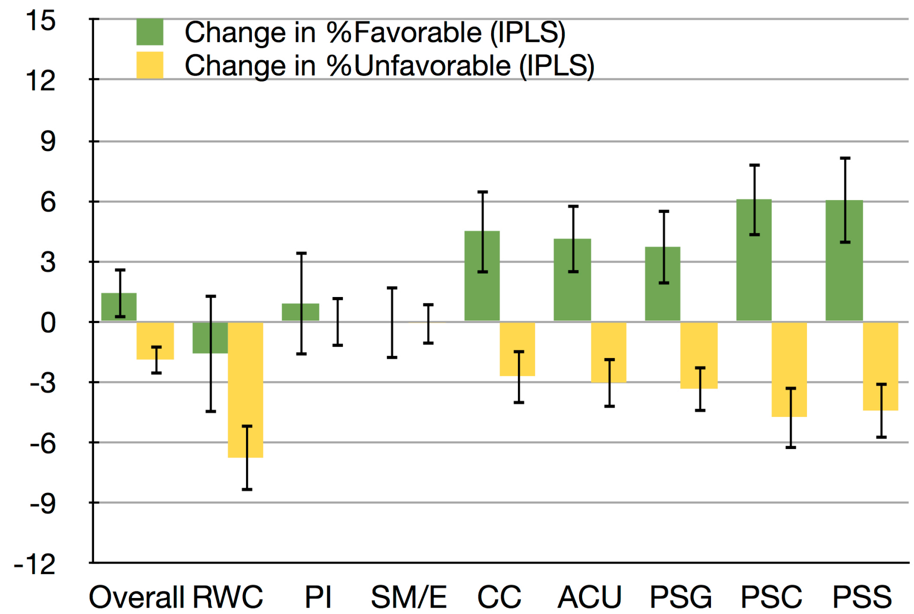
SWARTHMORE

Changes in CLASS

Standard first semester



IPLS second semester



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

SWARTHMORE

Example interest metric

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

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

Thanks to …

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

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

SWARTHMORE