Teaching physics to life science students — examining the role of biological context

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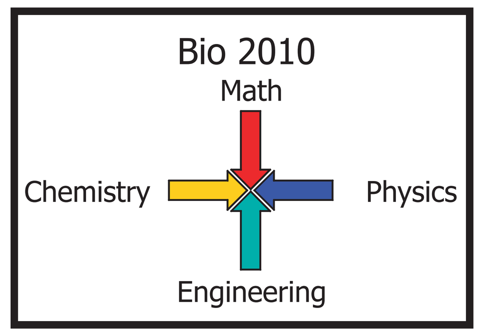
Why teach physics in biological context?



Recent reports from the **life science**[1] and **medical**[2] communities on training for their fields stress the importance of:

- a deep understanding of physics principles
- a high level of problem solving and quantitative skills
- the ability to **apply these principles and methods** to biological and medical contexts

The **cognitive apprenticeship** model[3] indicates the critical importance of **context** for student learning. Students learn new ideas best in a global context that they understand and value.

Studies of **transfer**[4] suggest that for students to be able to apply physics to another scientific field, such applications must be included in the learning process.

Finally, the reports and discussions with life scientists and physicians reveal that the **topics** covered by typical introductory physics courses are **not well matched** to the life sciences. The syllabus must be reformed as well (copies of our syllabi are available).

1. *BIO 2010: Transforming Undergraduate Education for Future Research Biologists,* National Research Council (Nat'l Academies Press, 2003).
2. *Scientific Foundations for Future Physicians,* HHMI-AAMC Committee (American Association of Medical Colleges, 2009).
3. For example, Collins, Seely Brown, and Holum, American Educator (Winter 1991).
4. For example, Schwartz, Bransford, and Sears, in *Transfer of Learning: Research and Perspectives* (Information Age Publishing, 2005).

Proposed research agenda

To assess effectiveness of teaching physics in biological context, compared to a traditional course:

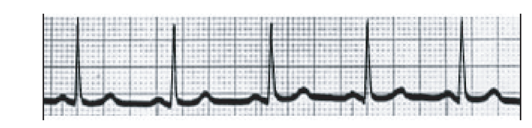
1. Do students find such courses more motivating?
2. Do students' attitudes in such courses improve?
3. Do students learn physics content and develop skills as well or better?
4. Are students able to apply physics in their downstream biology courses and research experiences?

Hypothesis: Yes to all!
Methods to address: CLASS, surveys, artifact-based interviews.

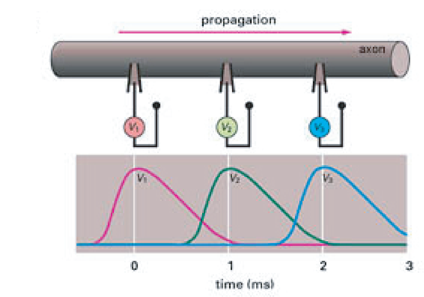
For designing effective biological contexts:

1. What characteristics make contexts effective for learning fundamental physics principles and skills?
2. What characteristics make contexts effective at creating an environment of expert practice?

Hypotheses:
for 1: seek contexts that map onto established effective materials
for 2: particularly effective if context is also familiar from everyday experience
Methods: student interviews, analysis of student written work



From University of Illinois Medical Center web site



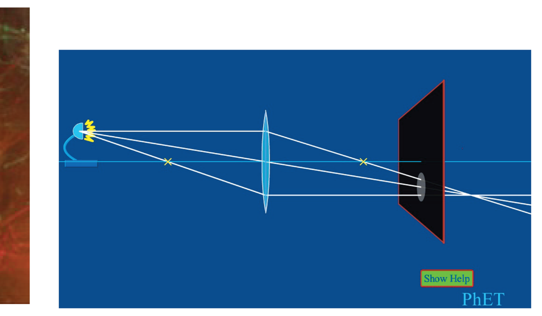
From Alberts *et al, Essential Cell Biology*

For a curriculum to be readily adoptable:

1. Is it congruent with strongly held physics instructor beliefs/values?
2. Is it adoptable with reasonable effort?
3. Does it produce easily observed improvements in student learning/behavior?
4. Does it degrade gracefully?

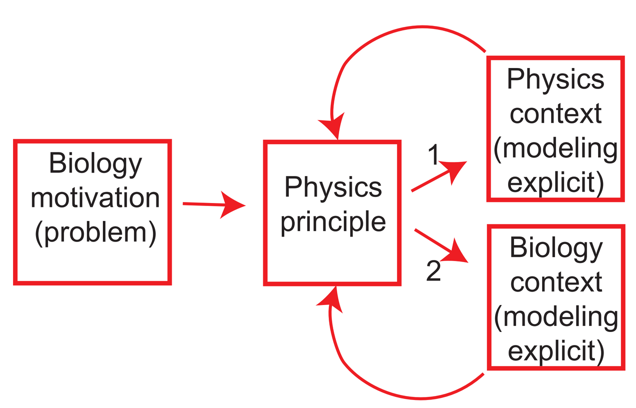
Methods: interview instructors with curricular artifacts, observe and interview faculty testing curriculum

Image from Nikon web site.



IPLS at Swarthmore and Minnesota

Each physics topic is organized around a few important biological examples used to motivate and then apply the physics principle. Instruction iterates between physics contexts and biological contexts:



Use established pedagogical strategies:

- ConcepTests, ranking tasks, comparison tasks
- context-rich problems
- problem-solving laboratories

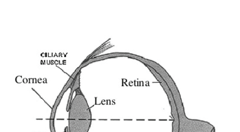
When possible, research-based physics context materials are adapted for the biological contexts.

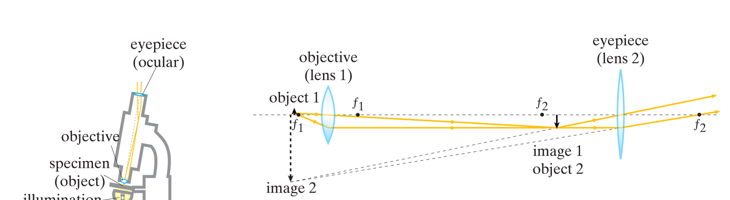
Geometric optics: biological contexts are vision and microscopy

Teaching single lenses:

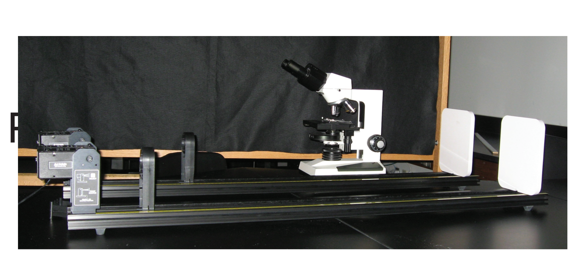
- physics contexts: fixed focal length lens, adjustable object/image locations
- human eye: adjustable lens, fixed image location

Paired ConcepTests and context-rich problems juxtapose both cases





From Eric Mazur, *Principles and Practice of Physics*



Laboratory: models of microscope optics and vision correction

- compare positions of different focal length "objectives"
- design and build microscope producing either real or virtual image (scaffolding based on UW Tutorials)
- correct for nearsightedness

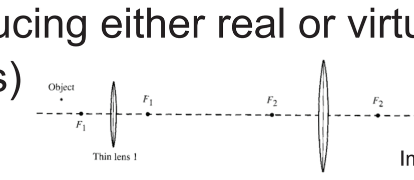


Image from *Tutorials in Introductory Physics* (McDermott *et al*).

Materials at http://materials.physics.swarthmore.edu/IPLSMaterials

Minnesota's course is a full year; Swarthmore's is second semester only (after standard first semester).

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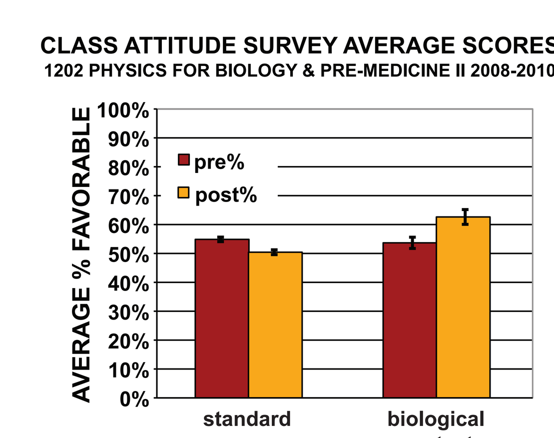
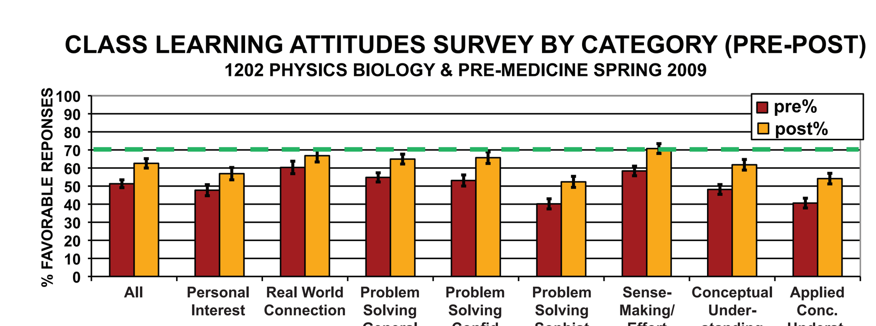
Preliminary results

Minnesota CLASS study

- improvement in all categories after 2nd semester course in biological context
- small decline after 2nd semester in standard course (CGPS and problem solving labs, no bio context)



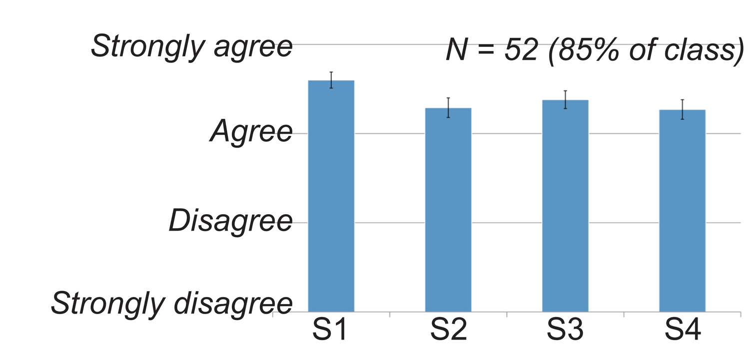
biological context responses by category (70% = average response from experienced TAs)



- 1st semester: decline in standard course, small or no improvement in biological context course

Swarthmore HHMI interest survey

HHMI evaluator (P. Kudish, 2010) found significant agreement with the following statements:

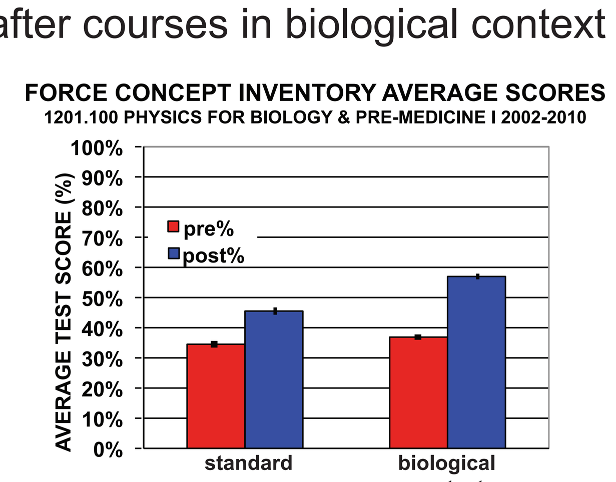


S1 "Including biological examples helped me enjoy physics more than if we had used non-biological examples."
S2 "Including biological examples helped me understand physics more than if we had used non-biological examples."
S3 "This course helped me think about biology in useful new ways."
S4 "Methods I learned in physics will be useful for me in my future career."

"I often found myself thinking, 'Oh, that's how it really works,' because I'd never thought about the physics behind some of the biological concepts I'm very familiar with."
—course evaluation comment, junior biology major

Minnesota concept surveys

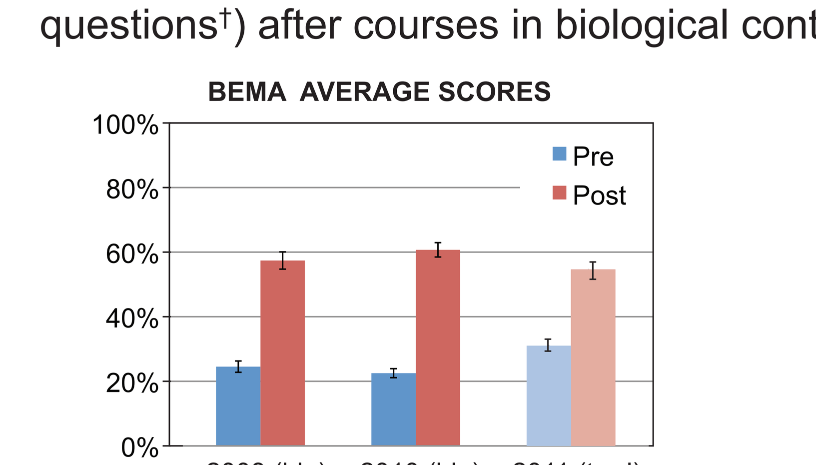
Greater improvement on FCI and BEMA after courses in biological context



BEMA pre scores range from 22 to 23%
BEMA post scores: 55% for biological context course
30-36% for standard course

Swarthmore conceptual surveys

Greater improvement on BEMA (27 relevant questions†) after courses in biological context



Note: response rate significantly lower in 2011 (respondents had higher than average grades)

†Did not study/test on transformers, Gauss's Law, or induced *E* field

"I wanted to tell you how well Physics 4L prepared me for my summer research.... The [work] we did [in class] 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 we have been discussing here. Recently we've been calculating currents through membrane potassium and sodium channels and accounting for leakage. Just thought you'd like to hear that your class was a success."
—unsolicited student email