Capstone examples for second semester IPLS: confocal microscopy and nerve signaling

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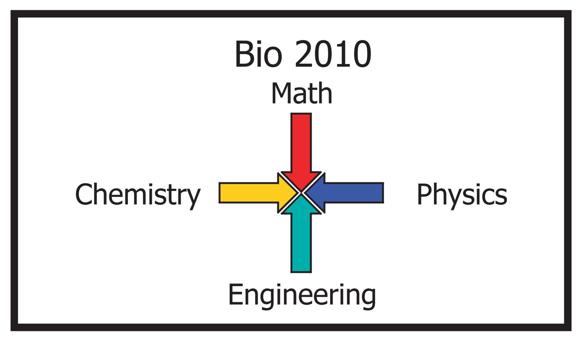
Biological contexts



The recent National Research Council report, *Bio 2010: Transforming Undergraduate Education for Future Research Biologists*, indicates that strong training in math, physics, chemistry, and engineering is critical for aspiring biologists.

Swarthmore College offers a focused second semester of introductory physics for life science majors and premedical students. (The first semester is shared with engineering students.)

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

Each physics topic is taught in both standard physics contexts and significant biological contexts:
- in class (introductory ideas, worked examples, conceptual questions)
- in homework and exam problems
- in the laboratory

Capstone examples give coherence to the biological contexts and a story line for the course. Confocal microscopy is the capstone for optics; nerve signaling, for electricity.

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Students gained a solid understanding of E&M in typical physics contexts:
- Good performance on quantitative exam problems
- BEMA average (out of 27, N = 58) pretest: 23% ± 10% (SD) posttest: 59% ± 18%
- Did not study/test on transformers, Gauss's Law, or induced electric field

† See for example Collins, Seely Brown, and Holum, American Educator (Winter 1991).

Confocal microscopy

Image from Nikon web site.

Confocal microscopy can produce three-dimensional images of biological samples with ~200-nm resolution. Many students have used Swarthmore's confocal microscope before taking physics; most know it is a critically important imaging technique in biomedical research.

- 3D images are constructed from a "stack" of planar images
- Planar images are obtained pixel by pixel by scanning a diffraction-limited focused laser beam over the sample
- Light from other planes is blocked by a pinhole

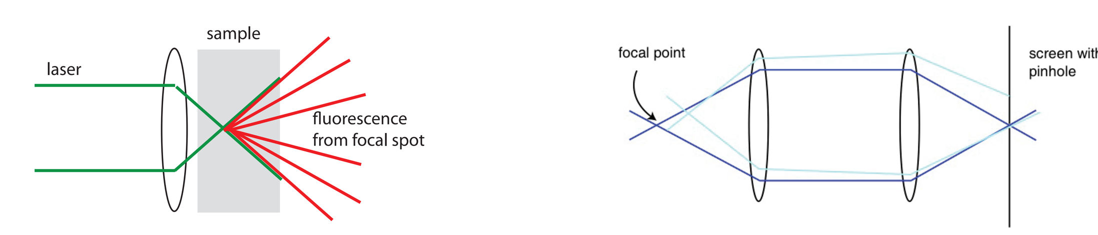


Image from Semwogerere and Weeks, 2005

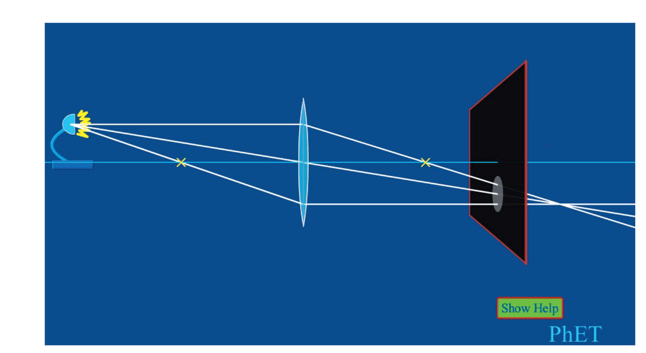
Understanding confocal microscopy combines geometric optics, depth of focus, and diffraction.

Constructing an image pixel by pixel is analogous to constructing multiple points on an image with ray diagrams!

If time permits, confocal microscopy also involves energy level structure and fluorescence.

Instructional sequence:
- *Pinhole image formation (mollusk vision).*
- *Image formation with single lenses (human vision).*
- *Image formation with lens combinations (compound microscope, both virtual and real final image)*
- *Diffraction through circular aperture*
- *Limit of resolution for two point sources*
- *Limit of resolution for image of two point sources (microscope resolution)*
- *Depth of focus (use PhET simulation)*
- *Confocal microscopy*

Instructional materials can be obtained from Catherine Crouch, ccrouch1@swarthmore.edu.

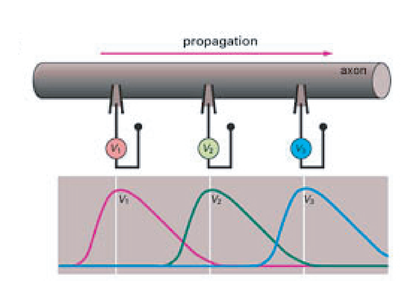


Dr. Crouch was later asked by a student to review confocal microscopy for a summer research group using Swarthmore's confocal microscope.

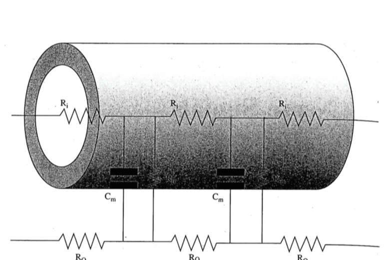
Nerve signaling

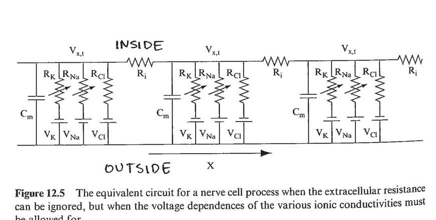
Understanding electrical signals in neurons motivates electrostatics as well as circuits.

Capstone discussion: how signal velocity depends on nerve diameter and myelination



From Alberts et al, Essential Cell Biology





"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 feedback

Instructional sequence:
- *Model charged cell membrane as parallel plate capacitor.*
- *Dielectric constant of membrane material increases capacitance.*
- *Introduce current as motion of ions through cylinder of conducting fluid subject to applied voltage.*
- *Resistance depends on shape of cylinder and concentration of ions (conductance).*
- *Introduce simple series and parallel resistor circuits (gel electrophoresis) and series RC circuits (defibrillator).*
- *Nerve cells can be modeled as complex resistor- capacitor circuits.*

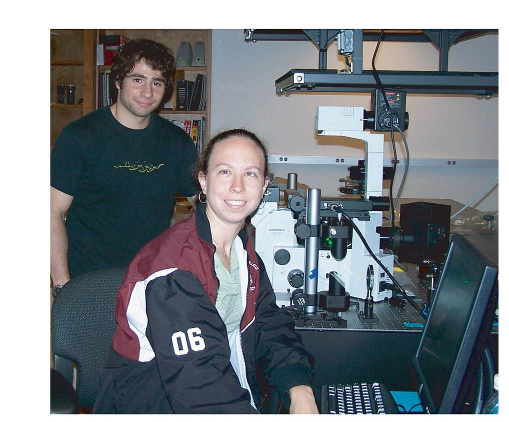
Student responses

Students expressed great enthusiasm for the biological contexts. Several students independently contacted Dr. Crouch after finishing the course, indicating that the course had helped them in summer life science research projects (and even EMT training!).

A pilot survey of student interest (2010) found substantial student agreement with the following statements: (1 = disagree, 4 = agree; N = 52 out of 61 enrolled; designed by P. Kudish)

"Including biological examples helped me enjoy physics more than if we had used non-biological examples." (3.60)
"This course helped me think about biology in useful new ways." (3.38)
"Understanding aspects of physics that we learned in this course are useful for solving real-world problems in medicine, the envirnoment, agriculture, and other topics in biology." (3.37)
"Methods I learned in physics will be useful for me in my future career." (3.27)

A *CLASS* study is presently underway.



"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

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