Reinventing the Introductory Physics Labs for Future Biologists

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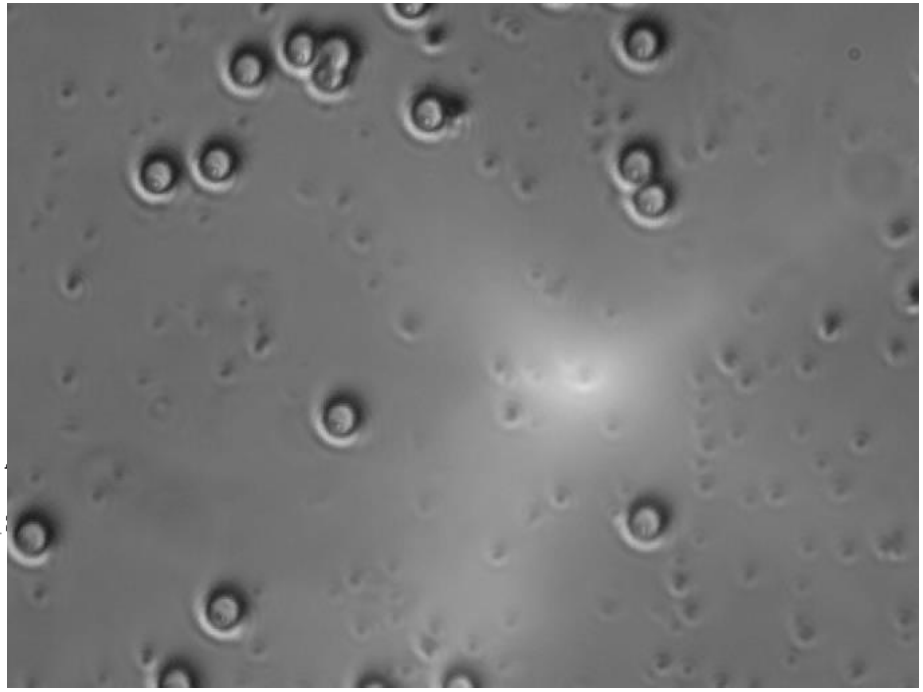
Director, Biophysics Graduate Program



NATIONAL EXPERIMENT
in Undergraduate Science Education

HHMI

What can Physics contribute to Biology and Medicine?

Experimental Tools for Diagnosis and Therapy

- MRI for high resolution imaging
- Proton therapy to eliminate diseased cells

Experimental Tools for Cell Biology

- Superresolution imaging (Betzig, Hell)
- NextGen Gene Sequencing (Quake)

Physics approaches: Quantitative Approaches to Complexity & Information

Physical principles: Mechanical and Optical Properties of Living Systems

What can Physics contribute to Biology and Medicine?

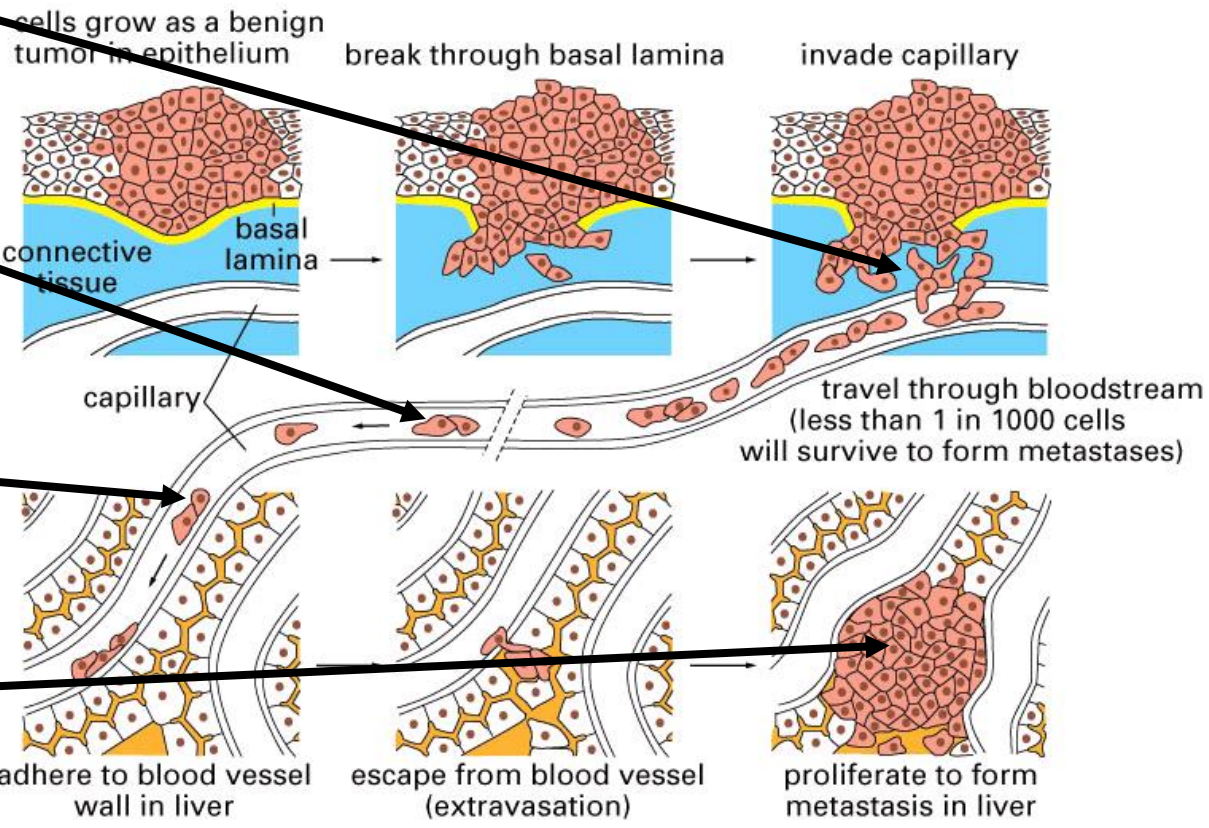
Example: The role of Mechanics in Cancer

Cells generate forces to migrate

Cells are deformed by fluid flow

Cells adhere to new tissue

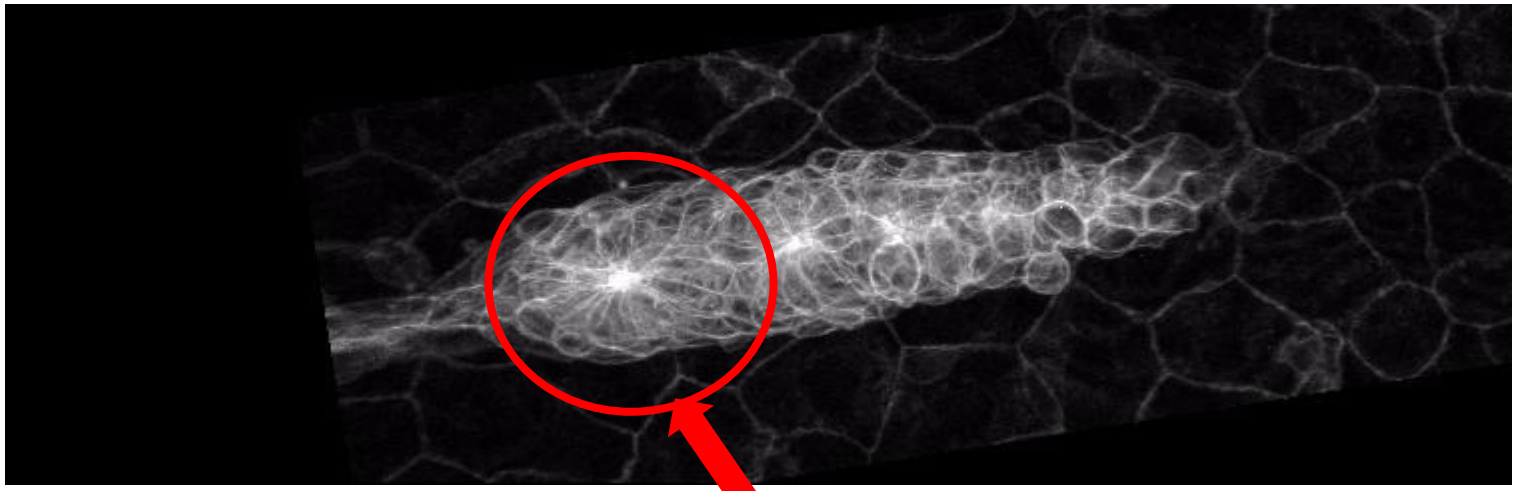
Cells grow in tissue with different stiffness



Cell arrangements and motion contain information about biology

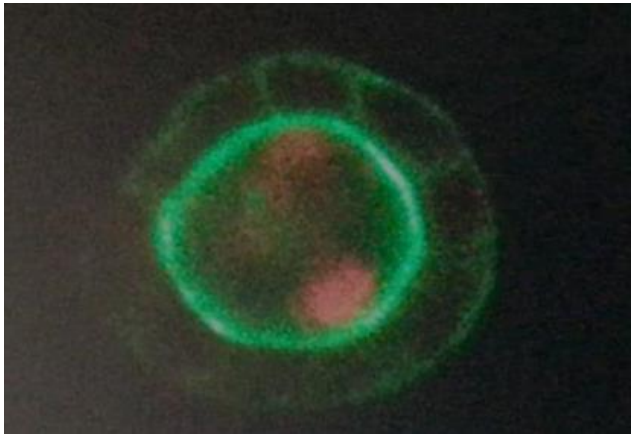
Primordium

D. Hemingway, WL, AJ Chitnis



Asinus

Will form Sensory Node



Future Vasculature

D. Hemingway, WL, K. Tanner

Physics of Living Systems is DIFFERENT from the Physics taught in many Introductory Courses

Motion on the scale of cells

Forces on the scale of cells

Random		Directed
(Forces/Motion)		(Forces/Motion)
Brownian Motion		*Fluid Flow* *Electrical*

Reinventing the Introductory Physics Labs (& Course) for Future Biologists

Physics Education

Joe Redish

Todd Cooke

Karen Carleton

Ben Dreyfus

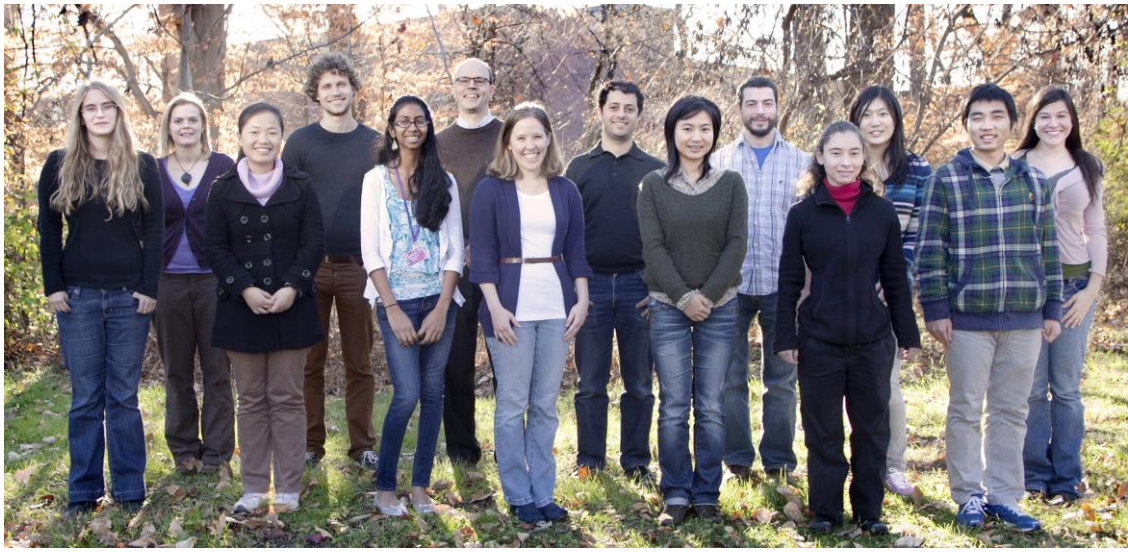
Ben Geller

Julia Gouvea

Kim Moore

Vashti Sawtelle

Biodynamics Research Lab



Joshua Parker – TA in 2011/2012

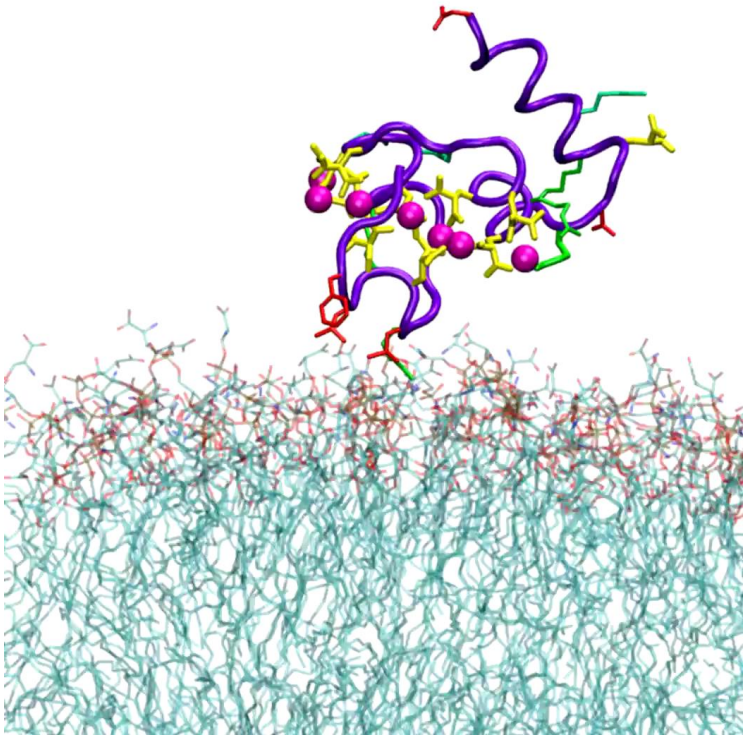
Ben Geller – Lab Development

John Giannini – Lab Development 2012/13

Kim Moore – Lab Development/ TA 2012/13

NEW in the Course: (1) Topical Shift

Physics @ Biological Scales: Example: Forces and motion



Blood Clotting Protein on Membrane, Molecular Dynamics Simulation
Ohkubo & Tajkhorshid, *Structure* 2008.

NEW in the Course: (2) Pedagogy Shift

Course Pedagogy Encourages Student Sensemaking

- Flipped classes with wiki pre-reading.
- Community-style labs.
- Interdisciplinary Dialogue.
  - Can you gain biological insights by measuring speed or another physical quantity?
  - Are Newton's laws useful to understand proteins, membranes, and cells?

Aims of Lab Development

- Build on Successful Community Lab Concept
  - Provide hands-on experience with relevant physics concepts
    - *Focus on Sensemaking*
  - Develop student research skills
    - *Focus on Experimental Design*

Additional Goals of our Labs:

- Convey a modern view of physics
- Foster interdisciplinary transfer
  - *"What biology do you learn from a physical measurement?"*
- Help students toward their career goals

Can we achieve these additional goals without sacrificing the success of the Community Labs?

Modern Instruments & Analysis Tools

Inverted Microscope (2K$)

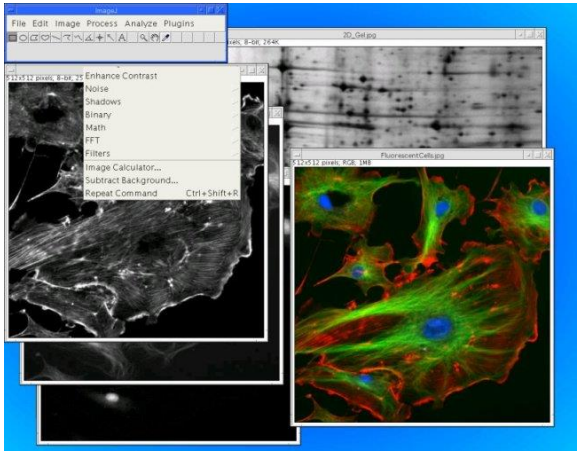
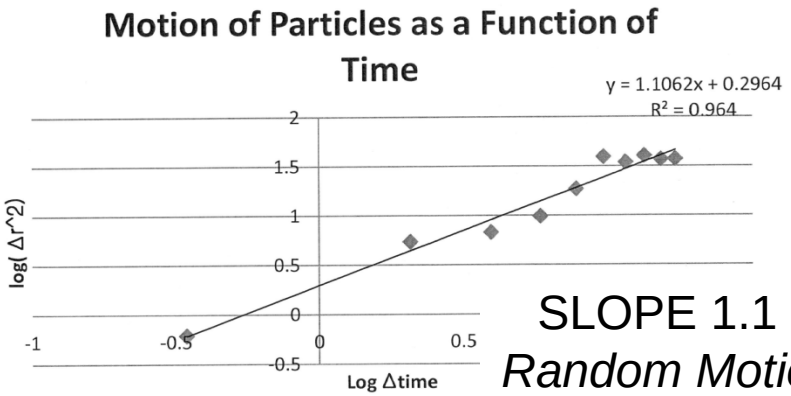


Image J (free)

Spectrometer (1.3K$)



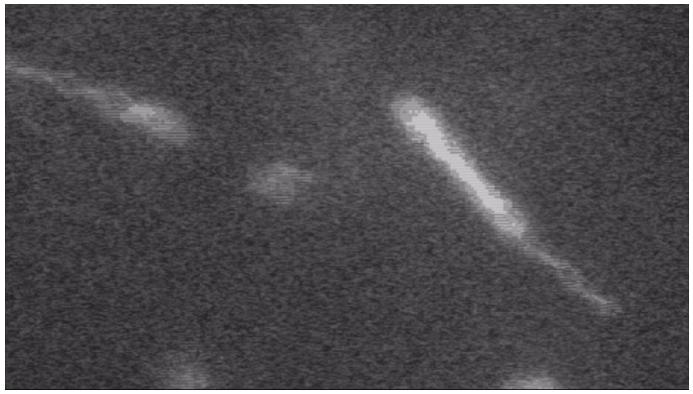
SLOPE 1.1

Random Motion

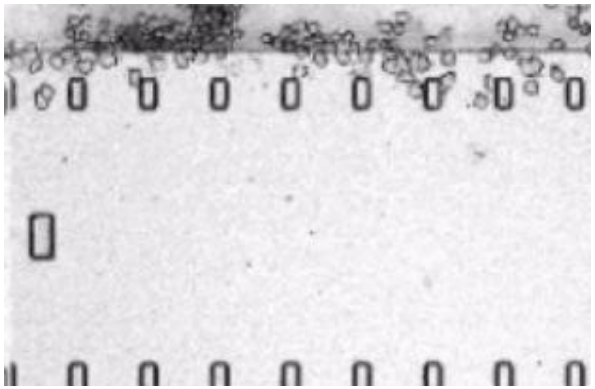
Modern Representations: Log-log plot

First Lab

Quantifying motion from Images and Videos (2 weeks)

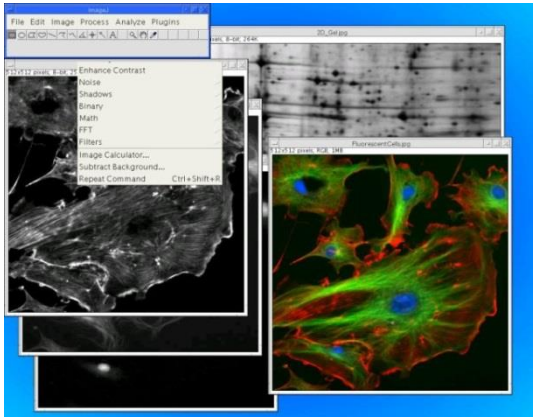


Bacteria



White blood cells

- *Analysis of cell motion using Excel and **ImageJ**.*

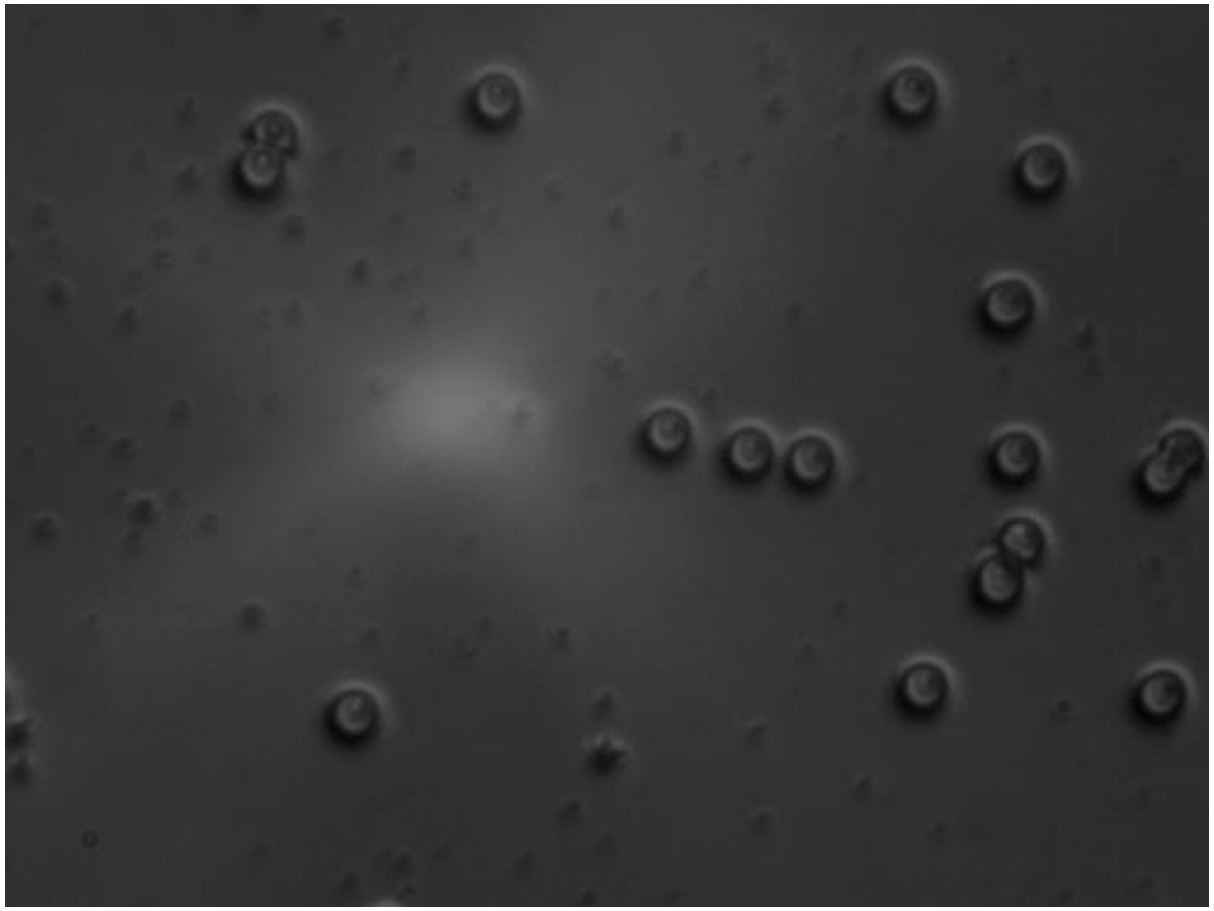


- *Fostering Interdisciplinary Transfer:*

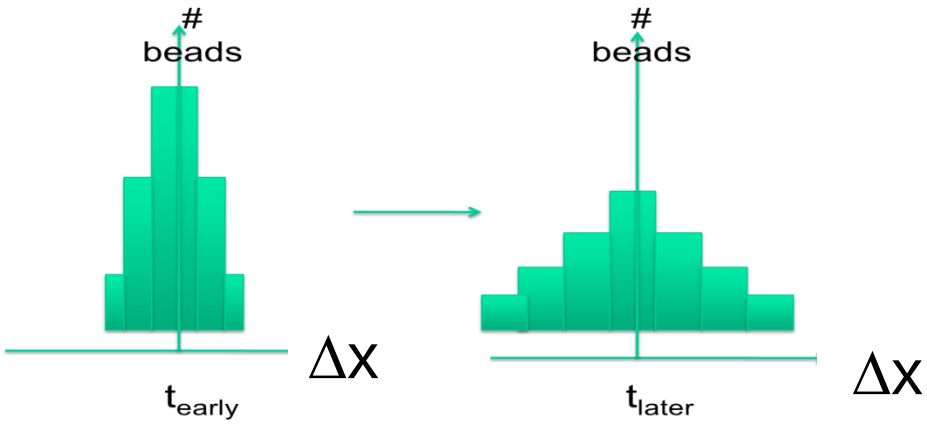
  Can you learn any biology from physical measurements?

EXAMPLE:
Brownian Motion

Inspired by laboratories developed by Mark Reeves (GW)
Mix of 1 and 5 micron beads, observed under the microscope



Measuring Brownian Motion



$\langle \Delta x \rangle = 0$

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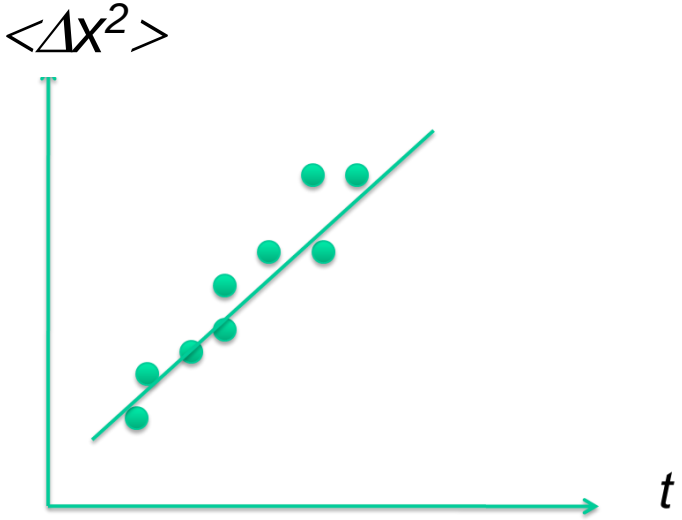


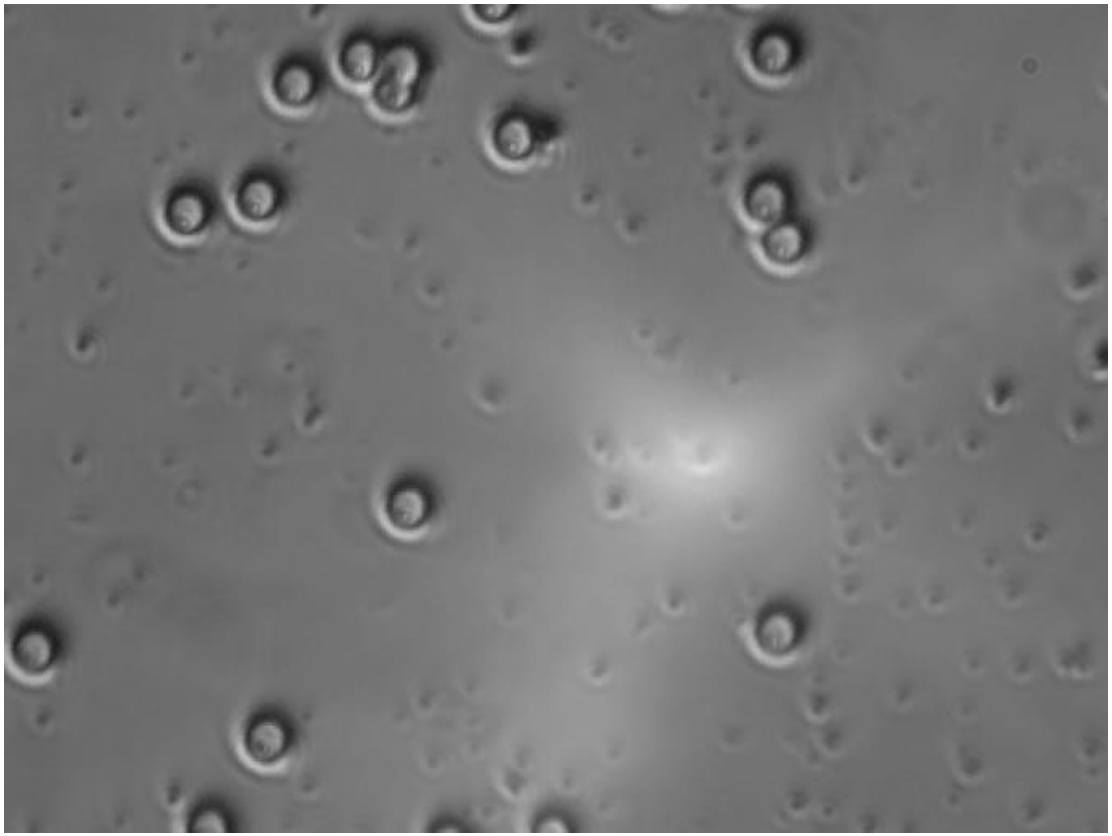
$$\langle \Delta x^2 \rangle = 4Dt$$

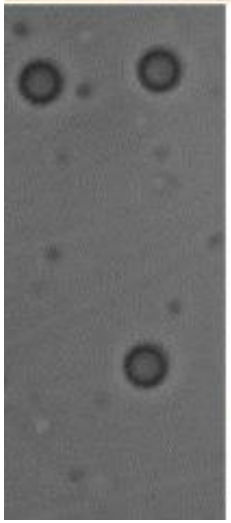
$$D = kT/6\pi\eta a$$

How does viscosity, bead size, mass, affect diffusion?

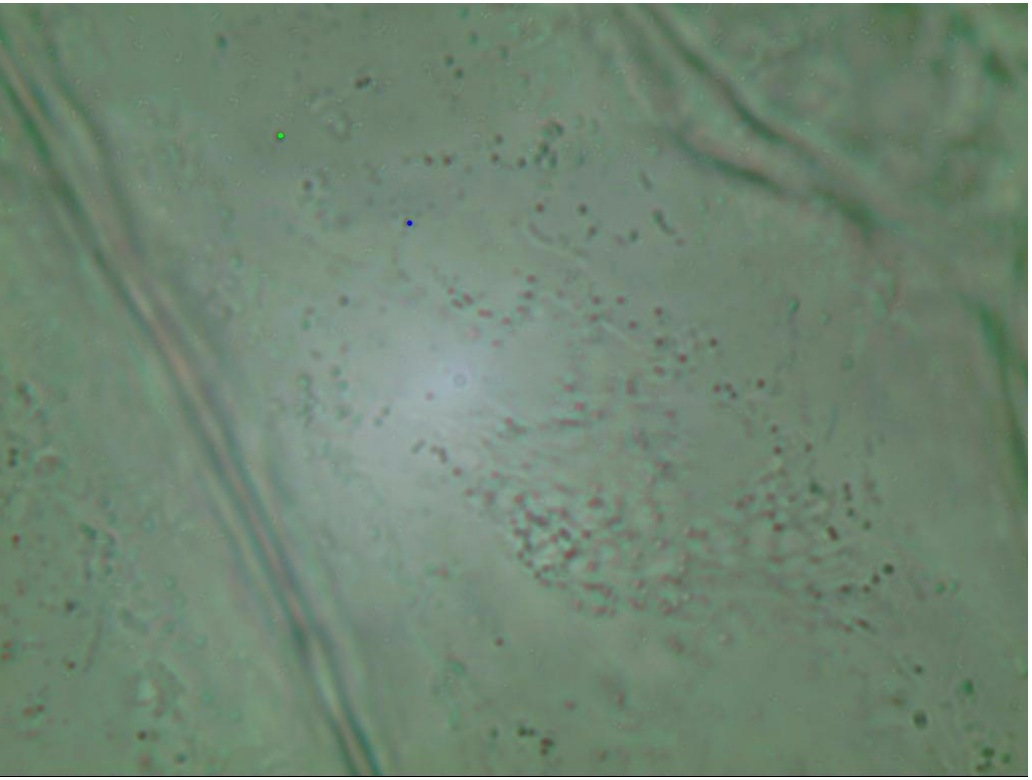
What is going on here?

A challenge suggested by Biophysics Colleague S. Sukharev

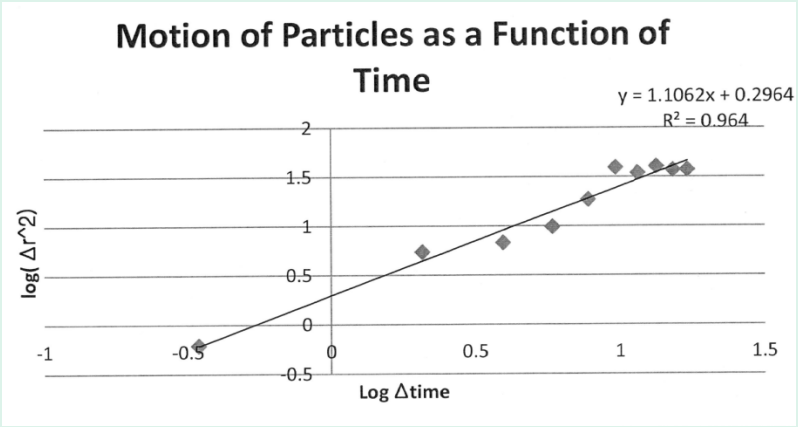




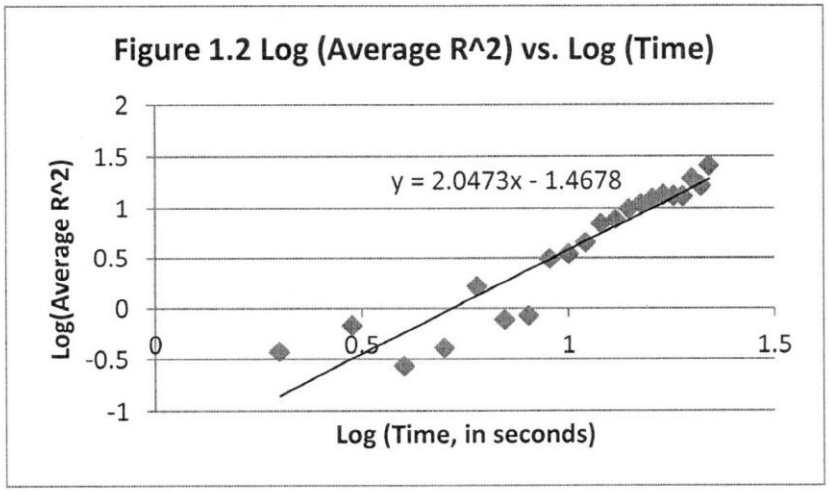
Interdisciplinary Transfer:
What Biology can we learn from a Physics Measurement?



Student Measurement Results



SLOPE 1.1 *Random Motion*



SLOPE 2.05 *Directed Motion*

Semester 1

Lab1: Quantifying motion from Images and Videos (2 weeks)

- Can you learn any biology from physical measurements?
- *Analysis of cell motion using Excel and ImageJ.*

Lab 2: Inferring force characteristics from motion analysis (2 weeks)

- How can information about forces be derived from a video?
- *Introduction to Video Capture & Analysis of Directed Motion and Resistive Forces.*

Lab 3: Observing Brownian motion at a microscopic scale (3 weeks)

- What does 'Random' motion look like? (inspired by M. Reeves)
- *Describing Diffusion & Random Motion.*

Lab 4: The competition between Brownian motion and directed forces

- How large a force is needed to transition from random to directed motion?
- *Distinguishing Random vs. Directed Motion*

Lab 5: Motion and Work in living systems (2 weeks)

- How much work is involved in Active Transport?
- *Classifying Motion and Examining Work in Onion Cells.*

Semester 2

Lab 1: Modeling fluid flow

- *Exploring Fluid Dynamics and the Hagen-Poiseuille (H-P) Equation.*

Lab 2: Analyzing electric forces in a fluid

- *Electrophoresis and Charge Screening in Fluids.*

Lab 3: Modeling electrical signal transmission along nerve axons

- *Testing Models of Signal Transmission.*
  (Adapted from labs by L. Cui UMBC & C. Crouch, Swarthmore)

Lab 4: Introducing geometric optics through experimental observations

- *Exploring Light and Lenses. (motivated by C. Crouch, Swarthmore)*

Lab 5: Analyzing light spectra and exploring implications for living systems.

- *Spectroscopy—Exploring Emission, Absorption & Evolutionary Adaptation.*
  (with K. Carleton, Biology)

Lab 6: Exploring complex absorption and emission in molecules. [1 week]

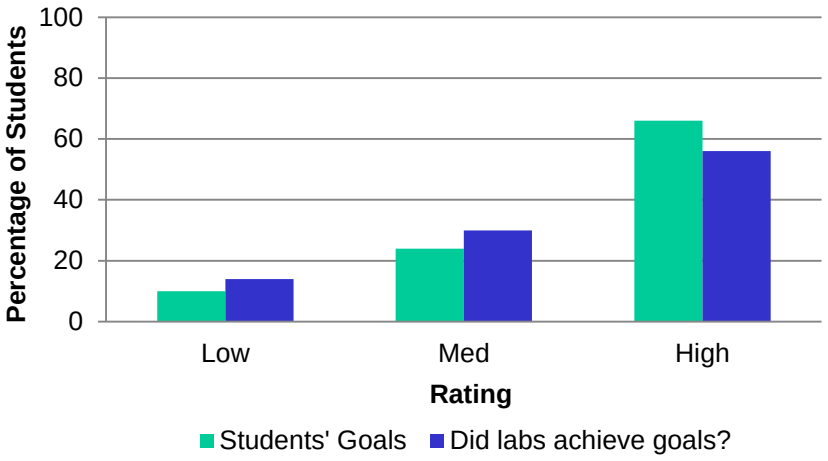
- *Spectroscopy & Fluorescence in Chlorophyll. (with K. Carleton, Biology)*

Preliminary Data Comparison

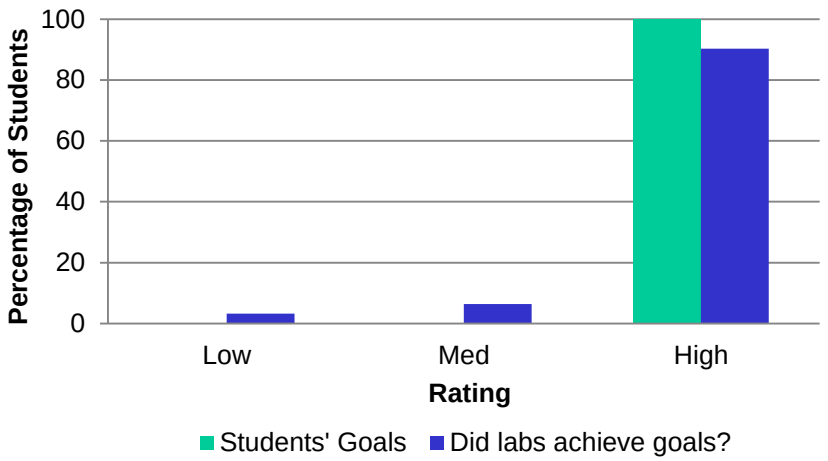
- Comparing to ISLE (2005) data from E. Etkina & S. Murthy, "Design labs: Students' expectations and reality," *AIP Conf. Proc.*, 818 (2006), N = 187
- Students (our largest N=31) were asked two questions:
  - **How important is each goal FOR YOU?**
  - **How successful were the labs in terms of achieving each goal?**
- **Goals:**
  - Learn to interpret experimental data
  - Learn to design your own experiment
  - Learn to work with other people
  - Learn to communicate ideas in different ways
  - Understand concepts better
  - Prepare for your future professional career

Lab Evaluations I
Interpret Data and Design Experiments

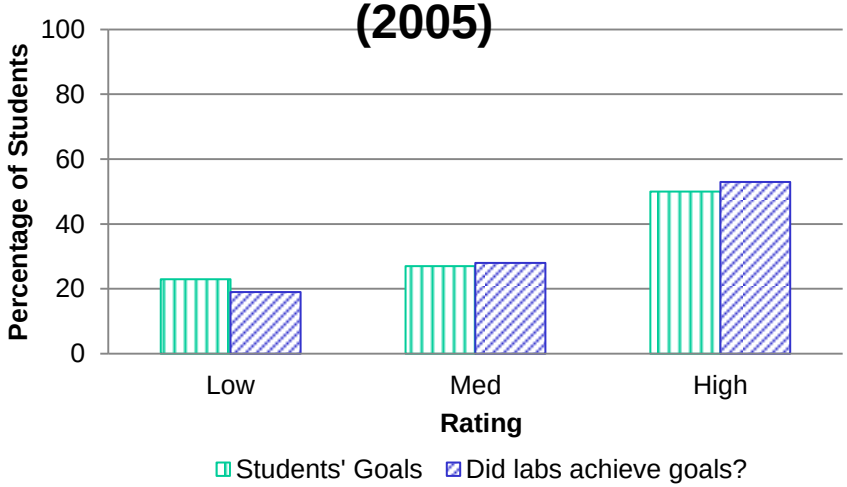
Interpret Data: ISLE (2005)



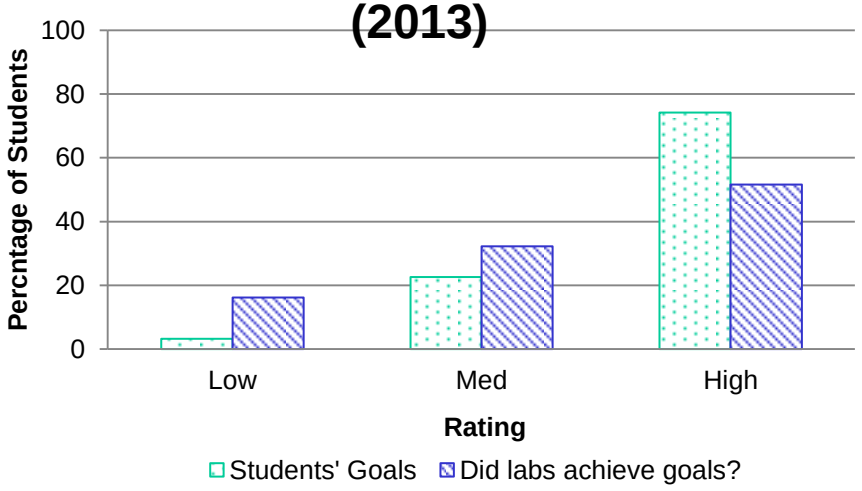
Interpret Data: NEXUS (2013)



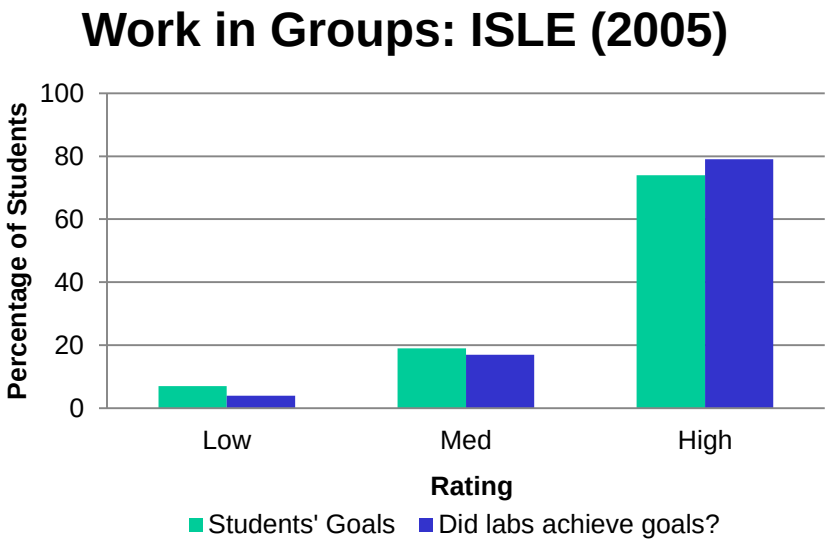
Design Experiments: ISLE (2005)

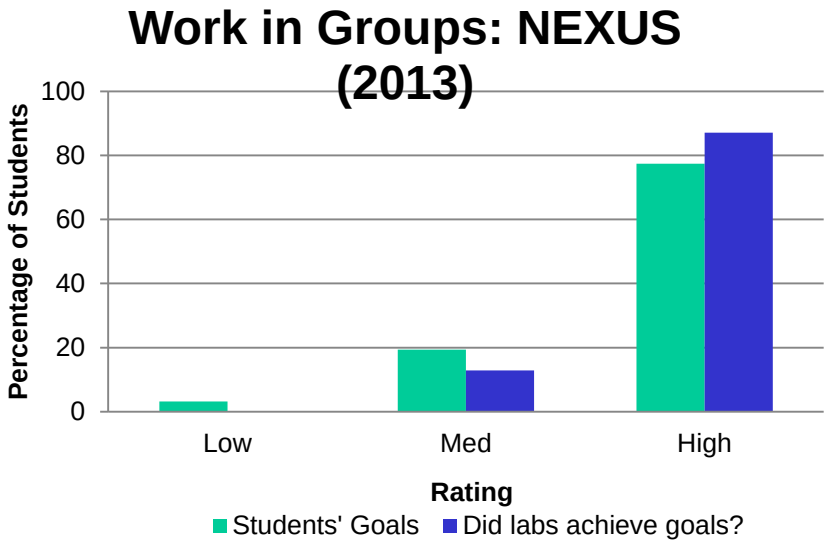


Design Experiments: NEXUS (2013)



Lab Evaluations II
Work in Groups

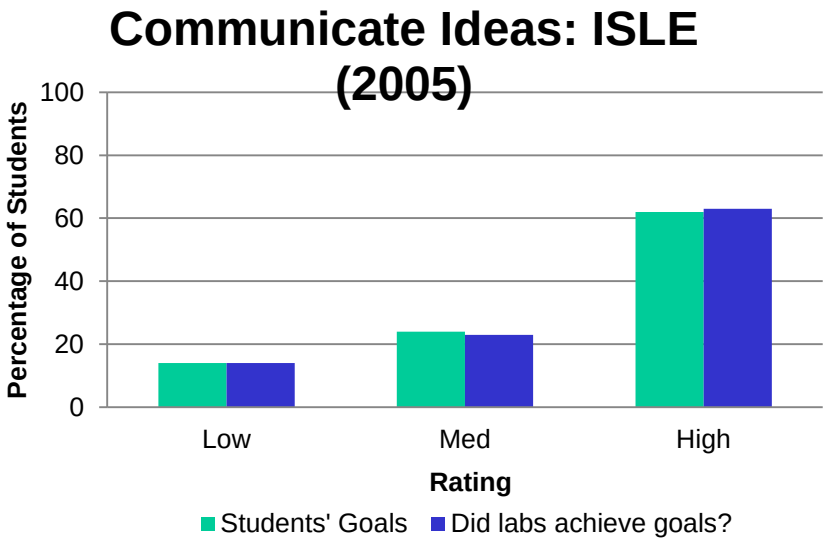


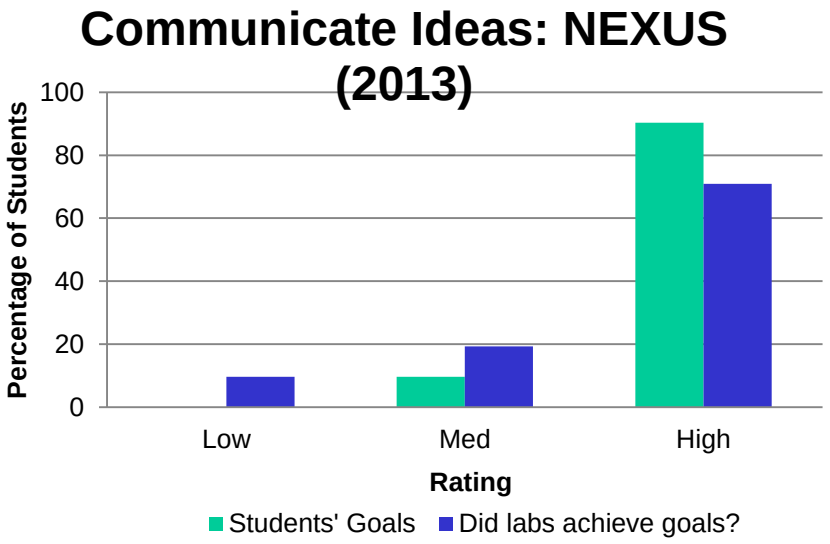


"If done on a mass scale with a bigger class, things could be different: people could be lazier or unengaged"

"There is more group work in this lab than in other labs that I have taken (I am mostly comparing to Chemistry labs). I think I benefit from this more because if there is ever anything that I don't understand, chances are one of my group members does."

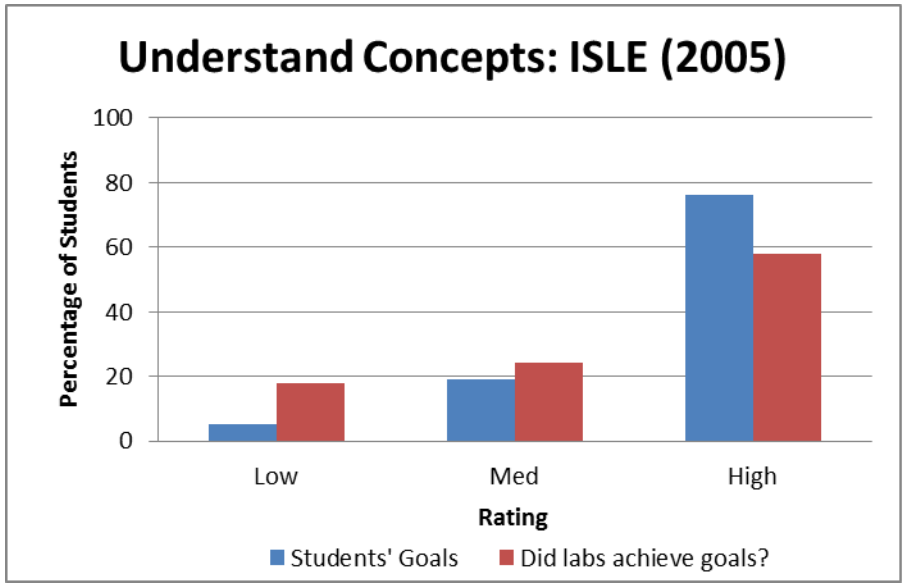
Lab Evaluations III
Communicate Ideas

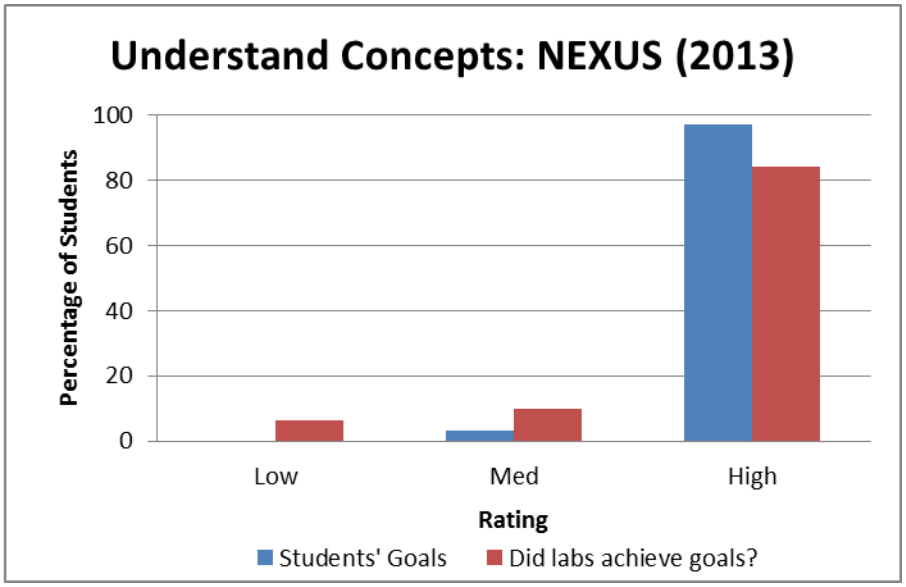




"I also like the reports, which are less data-filled than the chemistry labs. You don't just say what data you got from the lab, you actually discuss what it means and how it supports or doesn't support what was expected. That helps me to understand the concepts and their importance."

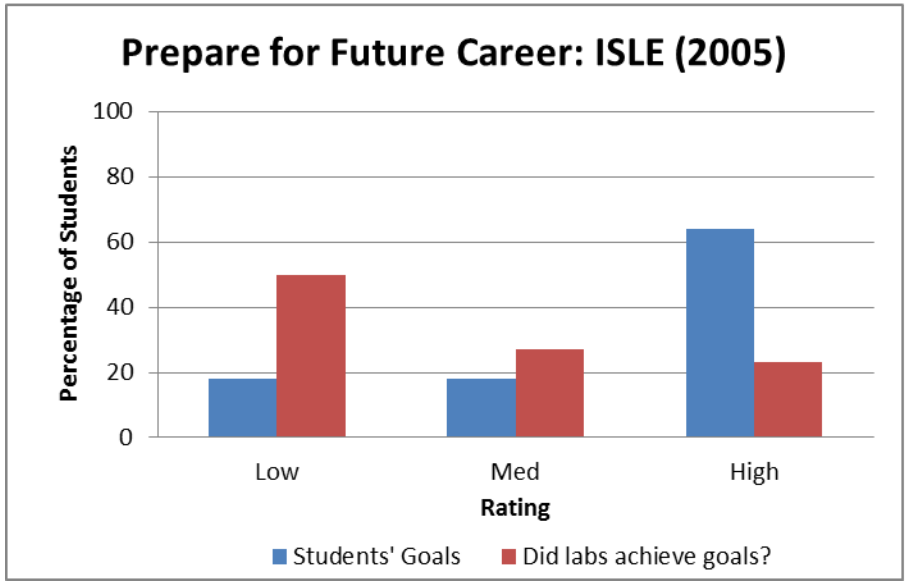
Lab Evaluations IV Concepts

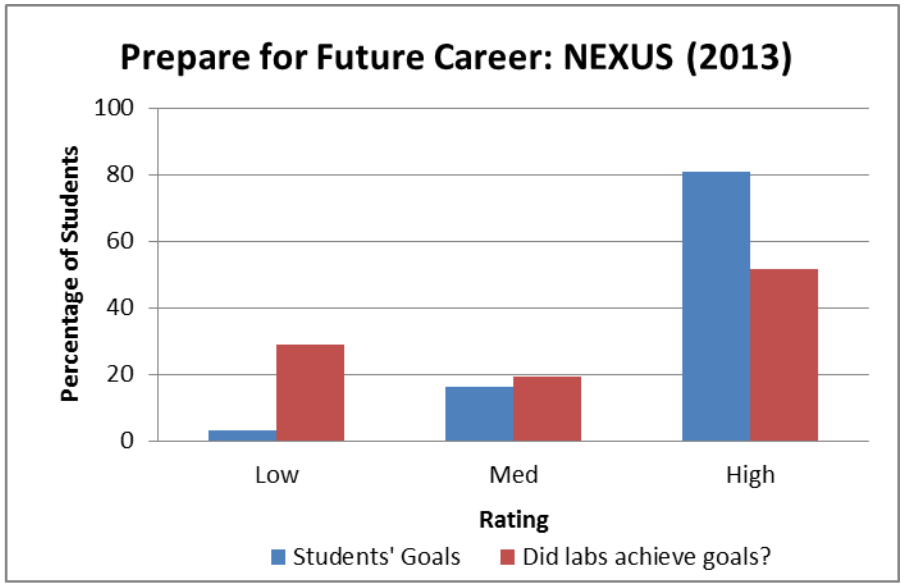




"I like the labs that we do. They allow me to better understand what we are learning in class. This enables me to remember what I learned and apply it to situations that I have not encountered in class."

Lab Evaluations V Relevance





"I didn't really have a good understanding of chemical bonding, free energy, or electricity when the semester started. Now, I feel that I understand these things very well in a physics context, and can apply them to other situations outside of the physics classroom comfortably."

Conclusions

- Built on Successful Community Lab Concept
  - Provide hands-on experience with relevant physics concepts
    - *Focus on Sensemaking*
  - Develop student research skills
    - *Focus on Experimental design]*

In addition our labs

- Convey a modern view of physics
  - Modern equipment, analysis and data representation tools
- Foster interdisciplinary transfer explicitly
  - *"What biology do you learn from a physical measurement?"*
- Help students toward their career goals

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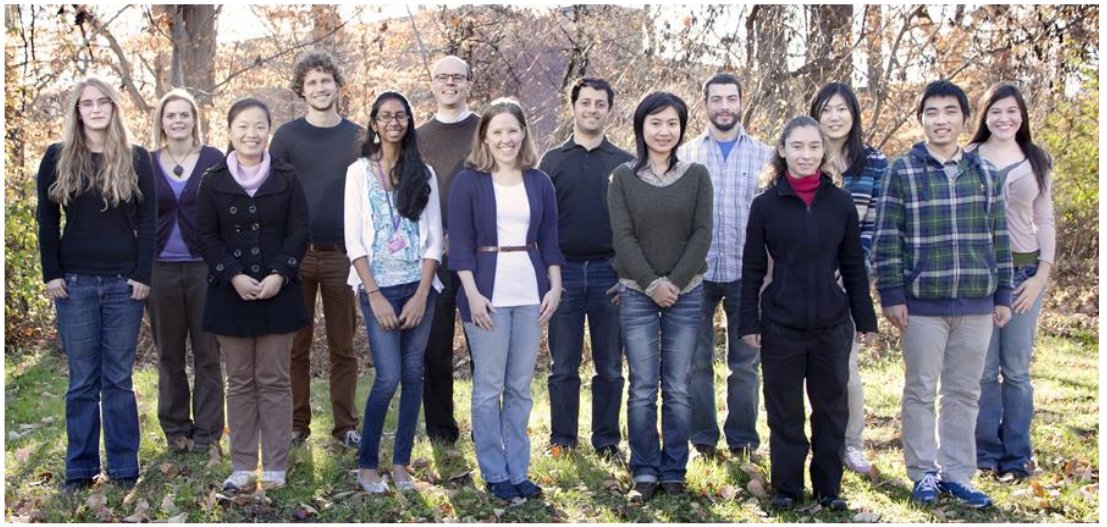

John Giannini – **Lab Development 2012/13**

Kim Moore – **Lab Development 2012/13**

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What's next

Large # of students in 2013/2014

Stay for the IPLS poster session!

- "Physics for Biologists: A Laboratory Curriculum Project" K. Moore

See Posters related to NEXUS:

PST2C02: "A Case Study in Leveraging Biology Ideas in Physics" (Sawtelle, Turpen, Gouvea)

PST2C04 "Like Dissolves Like: Unpacking Student Reasoning About Thermodynamic Heuristics" (Geller)

PST2C05: "Developing Biologically Relevant Mathematical Competence in Introductory Physics" (Gouvea, Turpen, Sawtelle)

PST2C06:"NEXUS/Physics: Rethinking Physics for Biology and Premed Students" (Redish)

PST2C13:"Negative Energy: Why Interdisciplinary Physics Requires Blended Ontologies" (Dreyfus).

EE06 (Tues., 4:50pm) "A Case Study in Leveraging Biology Experiences in Physics" (Sawtelle)

PER Wednesday, 8 pm "Research on a Laboratory Curriculum for NEXUS/Physics"

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