

# My Students Are Smarter Than Me!

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HHMI Quantitative Biology/Bio Math

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## “ Support your claims with data.”

Today's students face new pressures from the rapidly changing science and from a globally competitive market. If students only study in their majors, then their options will be limited. Biology has matured to the point where math and computer science are needed to make sense of the vast datasets. If a student seeks a research career, he or she had better pursue an education that enhances his or her quantitative skills. Since our students' needs are changing, what must we do as their teachers to keep up with the changing demands? How can we retool ourselves and our courses? Do we need new courses? Should we team teach more? Can we tweak what we have and honestly meet the needs of our students? This presentation will offer some answers and invite an honest discussion from the audience.

Today's students face new pressures from the rapidly changing science and from a globally competitive market.

# New Interdisciplinary Fields and Methods

Proteomics

Bioinformatics

Genomics

Systems Biology

Synthetic Biology

Computational Biology

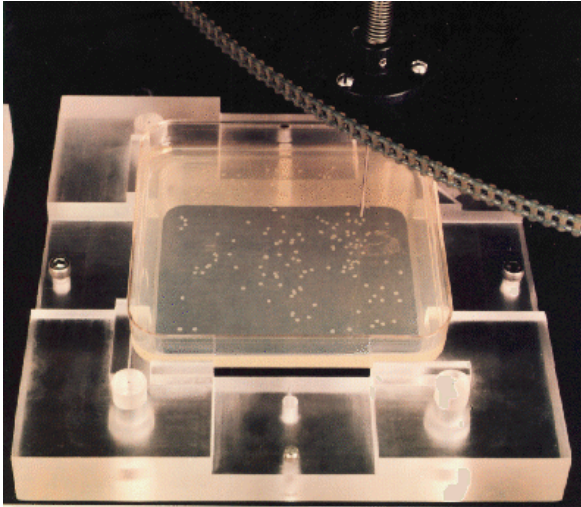
Metabolomics

Climate Modeling

Bioengineering

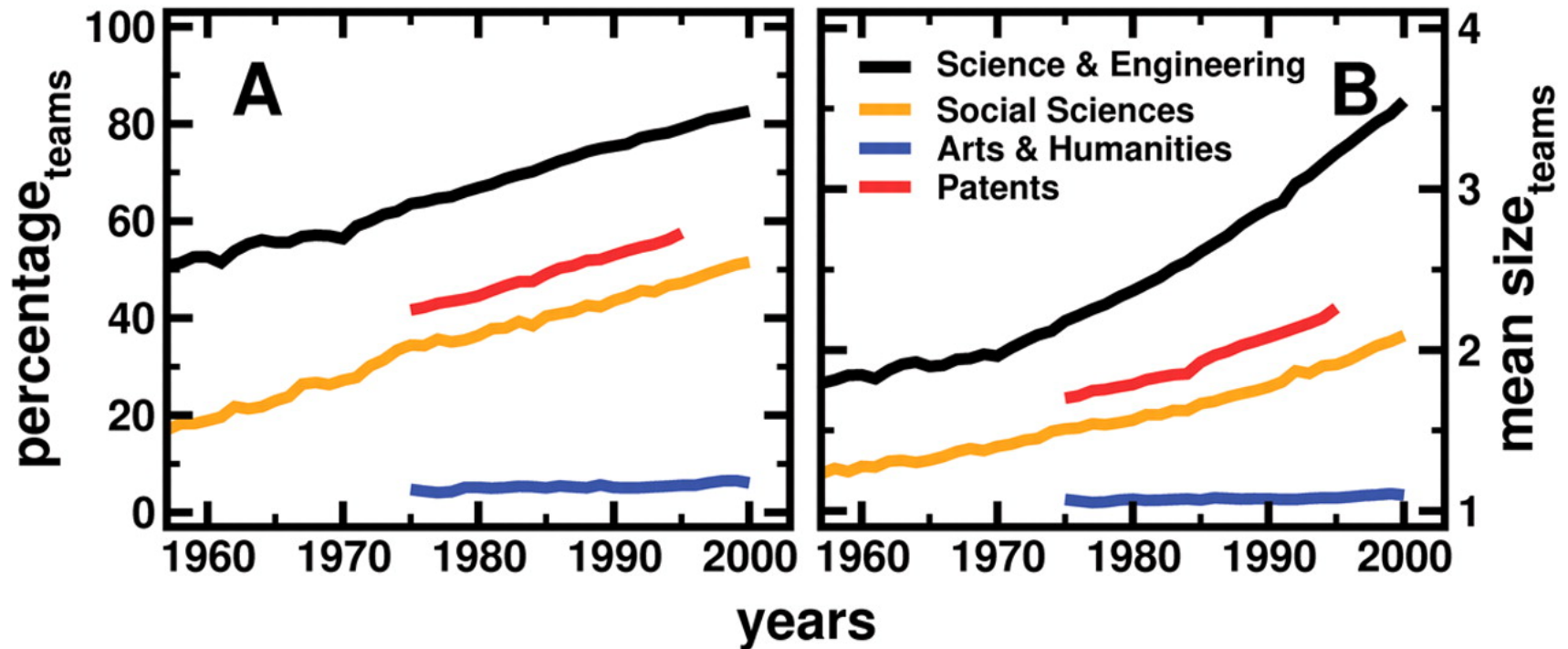
Conservation Biology

# High Throughput & Automated Data Collection



# Collaborations Are More Common

Team-authored publications





My PhD involved  
cloning & sequencing  
a cDNA and  
characterizing the  
protein.



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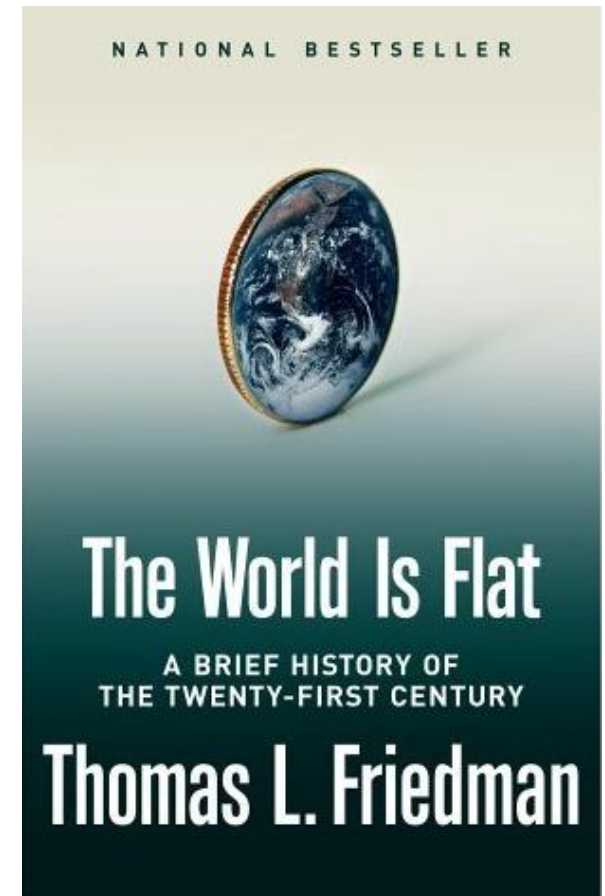
[illegible]



# The World Is Flat: A Brief History of the Twenty-First Century

10 "flatteners" leveling the global playing field:

- #1 Collapse of Berlin Wall
- #2 Netscape
- #3 Workflow software
- #4 Open sourcing
- #5 Outsourcing
- #6 Offshoring
- #7 Supply chaining
- #8 Insourcing
- #9 In-forming (*e.g.*, Google)
- #10 Personal digital devices



# The World Is Flat: A Brief History of the Twenty-First Century

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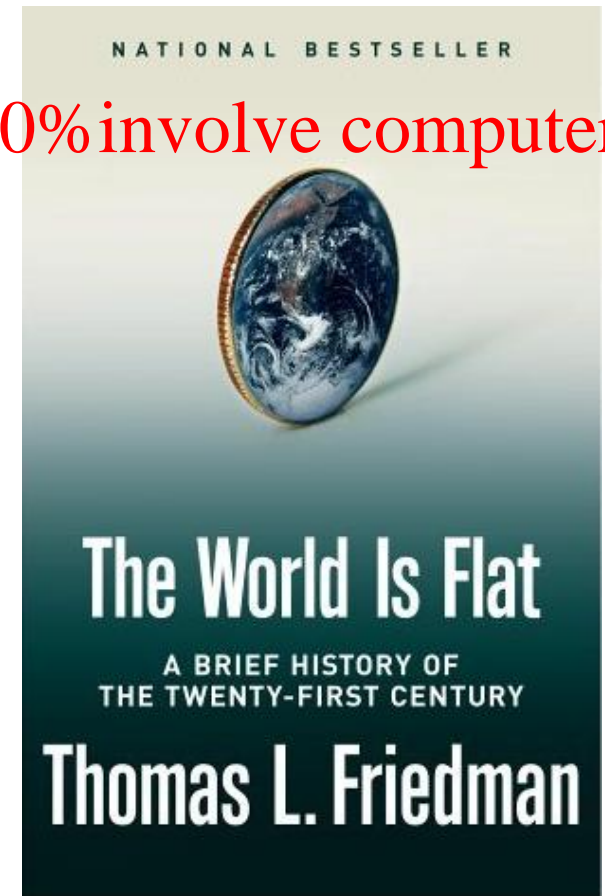
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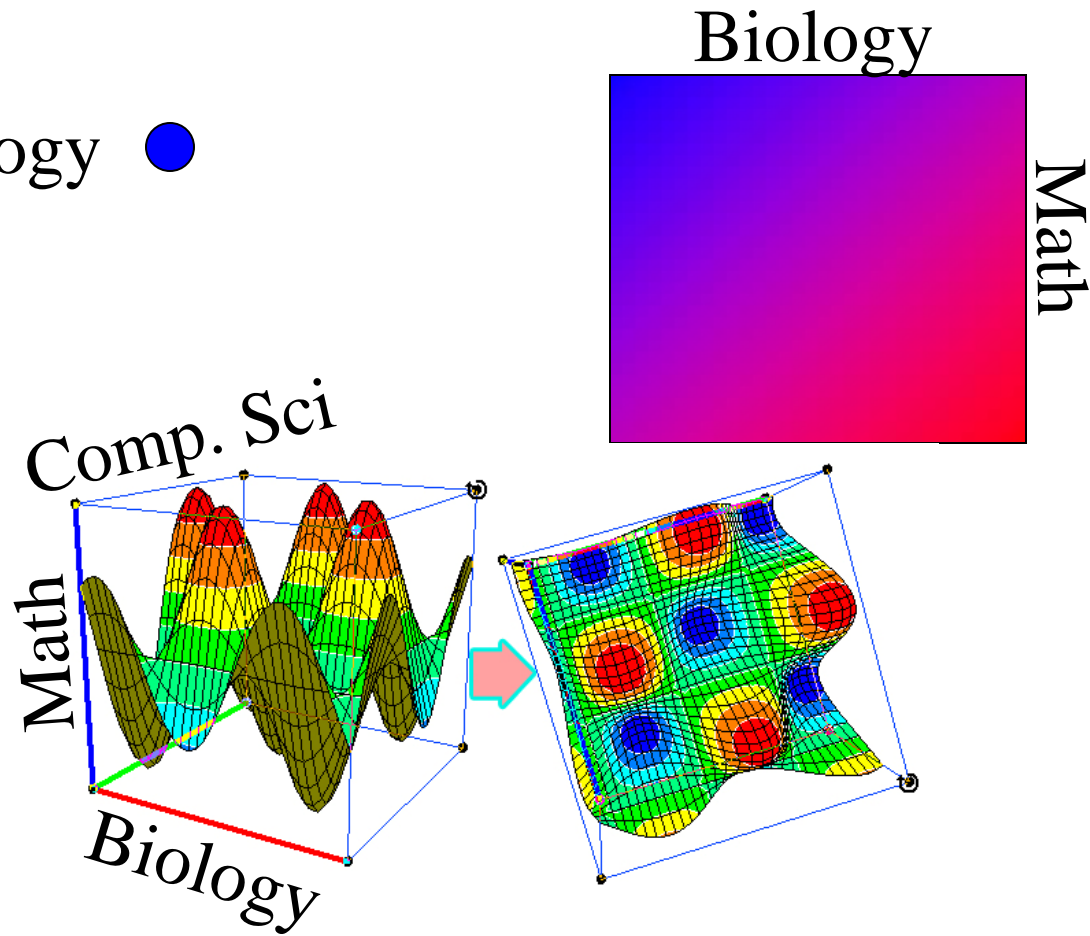
60% involve computers



If students only study in  
their majors, then their  
options will be limited.

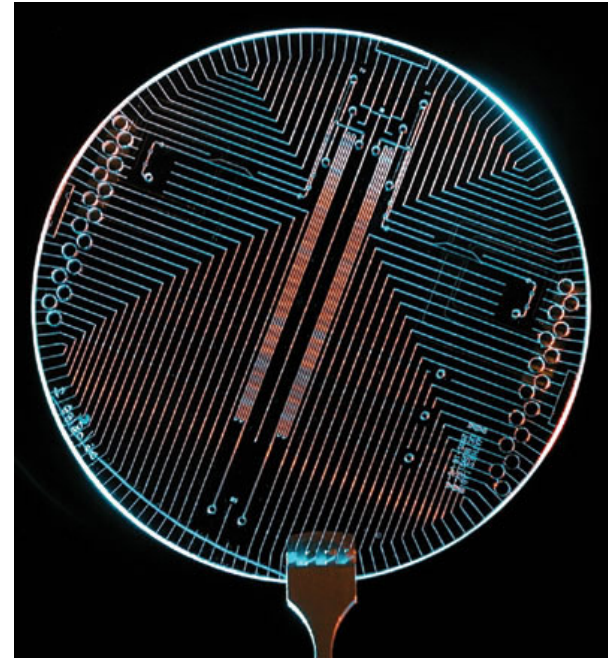
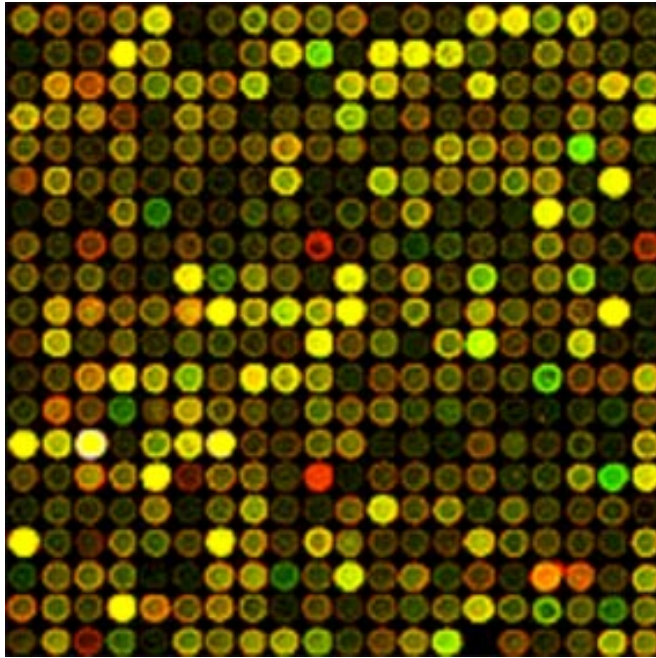
# Will your students be multi-dimensional?

Biology ●



## Why hire three people, when one will do?

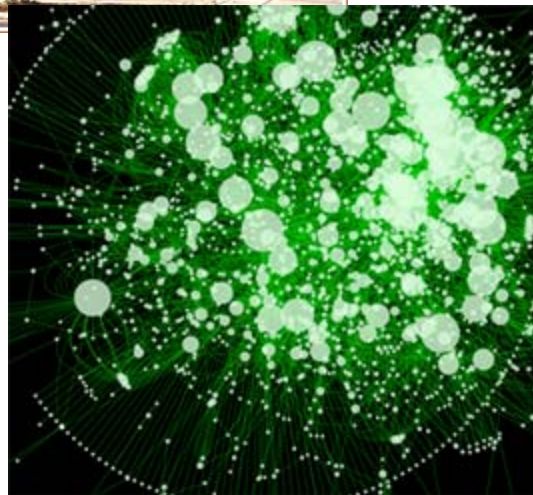
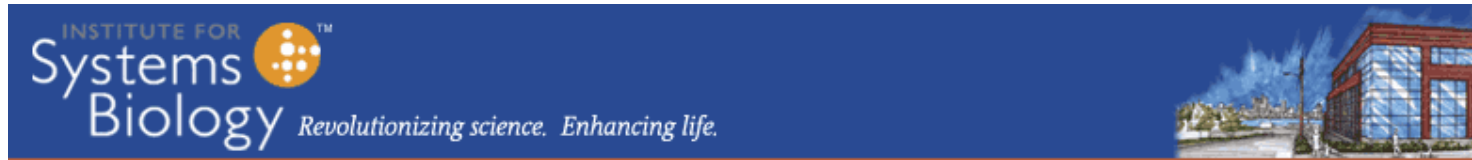
# Do you use methods learned after graduate school?



We need to prepare our students for a new landscape that changes like a screen saver.



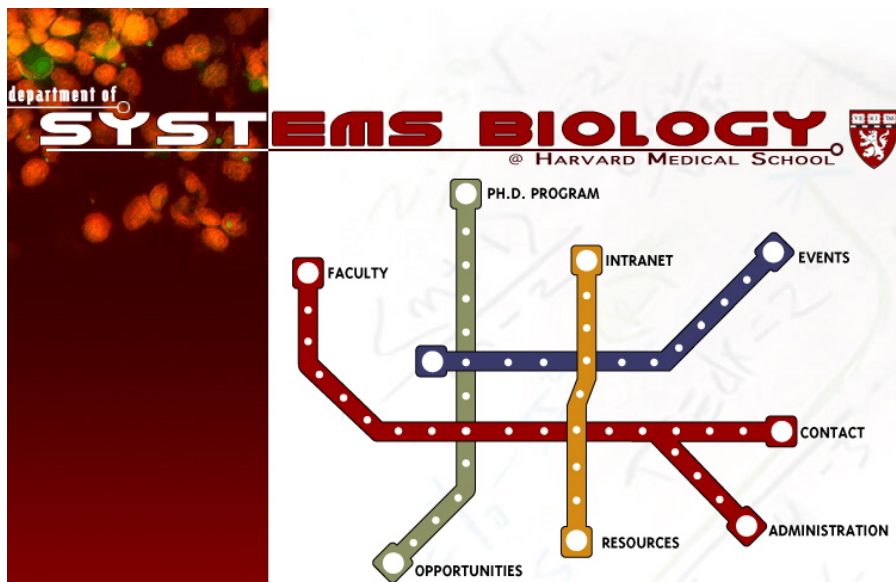
# Where will your students go to graduate school?



**Cytoscape**

*An Open Source Platform for  
Network Analysis and Visualization*





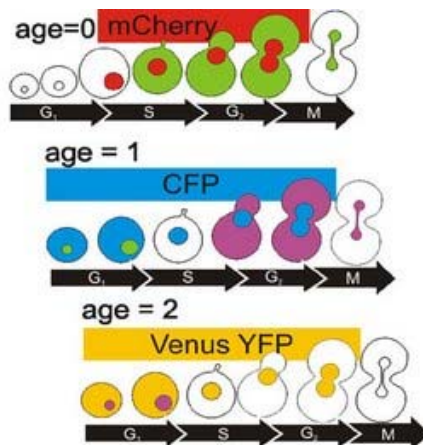
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?

What questions will they ask together?



# SynBERC

Synthetic Biology Engineering Research Center

## Investigators

### Jay Keasling, Director

University of California, Berkeley  
Department of Chemical Engineering  
Department of Bioengineering



### Wendell Lim, Deputy Director

University of California, San Francisco  
Department of Cellular and Molecular Pharmacology  
Department of Biochemistry and Biophysics



## Thrust Leaders

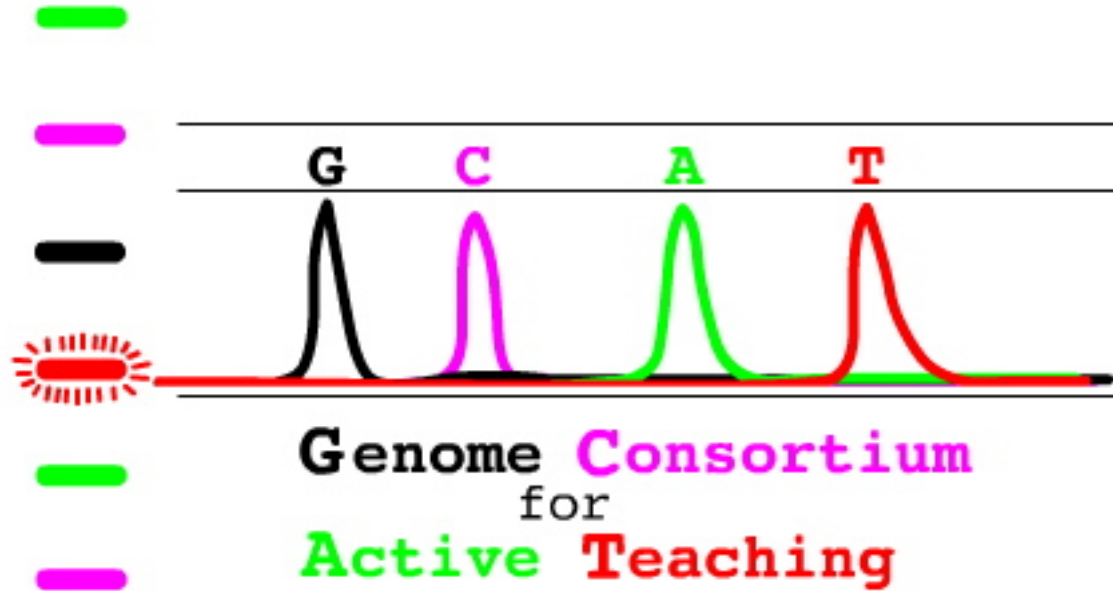
Parts	Wendell Lim	Cellular & Molecular Pharmacology, Biochemistry & Biophysics	UCSF
Devices	Drew Endy	Biological Engineering	MIT
Chassis	George Church	Genetics	Harvard
Human Practices	Kenneth Oye	Political Science, Engineering Systems	MIT
	Paul Rabinow	Anthropology	UCB

## Research Members

P = parts D = devices C = chassis H = human practices		
name	department	institution
J. Chris Anderson <b>PDC</b>	Bioengineering	UCB
Adam Arkin <b>PDC</b>	Bioengineering	UCB
Carlos Bustamante <b>PD</b>	Physics, Molecular & Cell Biology, Chemistry	UCB
George Church <b>C</b>	Genetics	Harvard
Raul Cuero <b>D</b>	Chemical Engineering	PVAMU
Drew Endy <b>PDC</b>	Biological Engineering	MIT
Michael Gyamerah <b>PD</b>	Chemical Engineering	PVAMU
Kristala Jones Prather <b>DC</b>	Chemical Engineering	MIT
Jay Keasling <b>DC</b>	Chemical Engineering	UCB
Thomas Knight <b>PDC</b>	Computer Science and Artificial Intelligence, Electrical Engineering and Computation	MIT

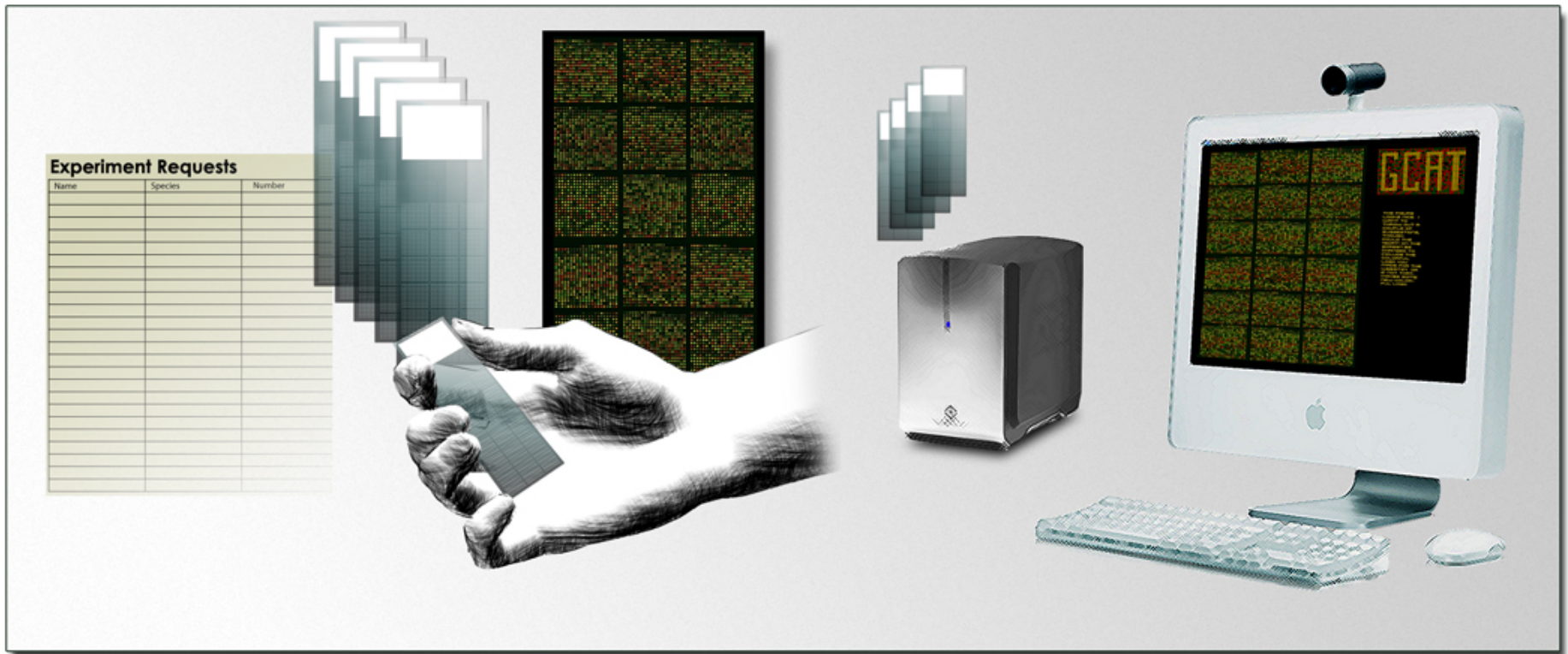
Biology has matured to the point where math and computer science are needed to make sense of the vast datasets.

# Seven Year Collaboration; Three Countries



[www.bio.davidson.edu/GCAT](http://www.bio.davidson.edu/GCAT)

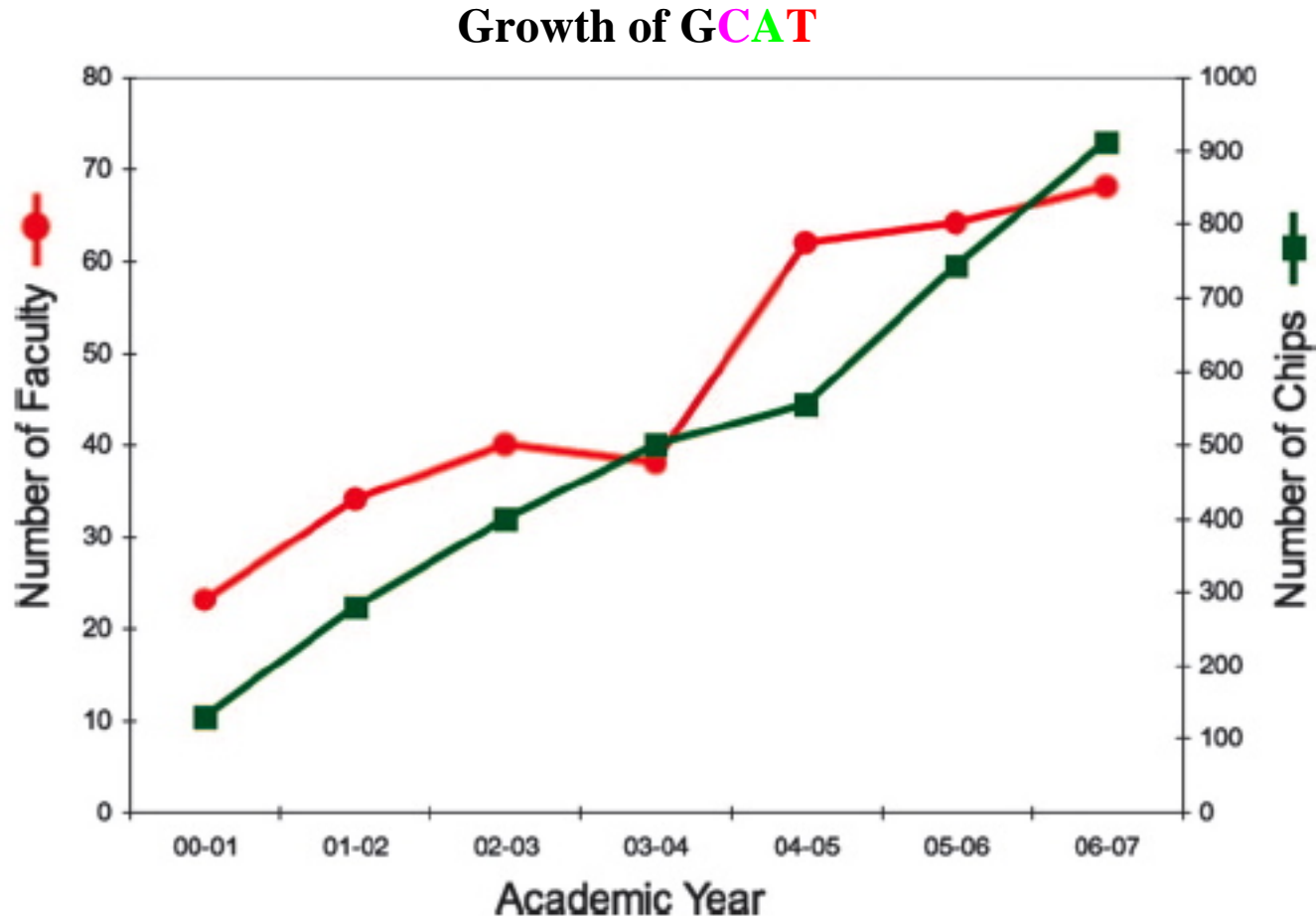
# G**CAT** Makes DNA Chips Affordable for ALL Students



Waksman Foundation  
for Microbiology

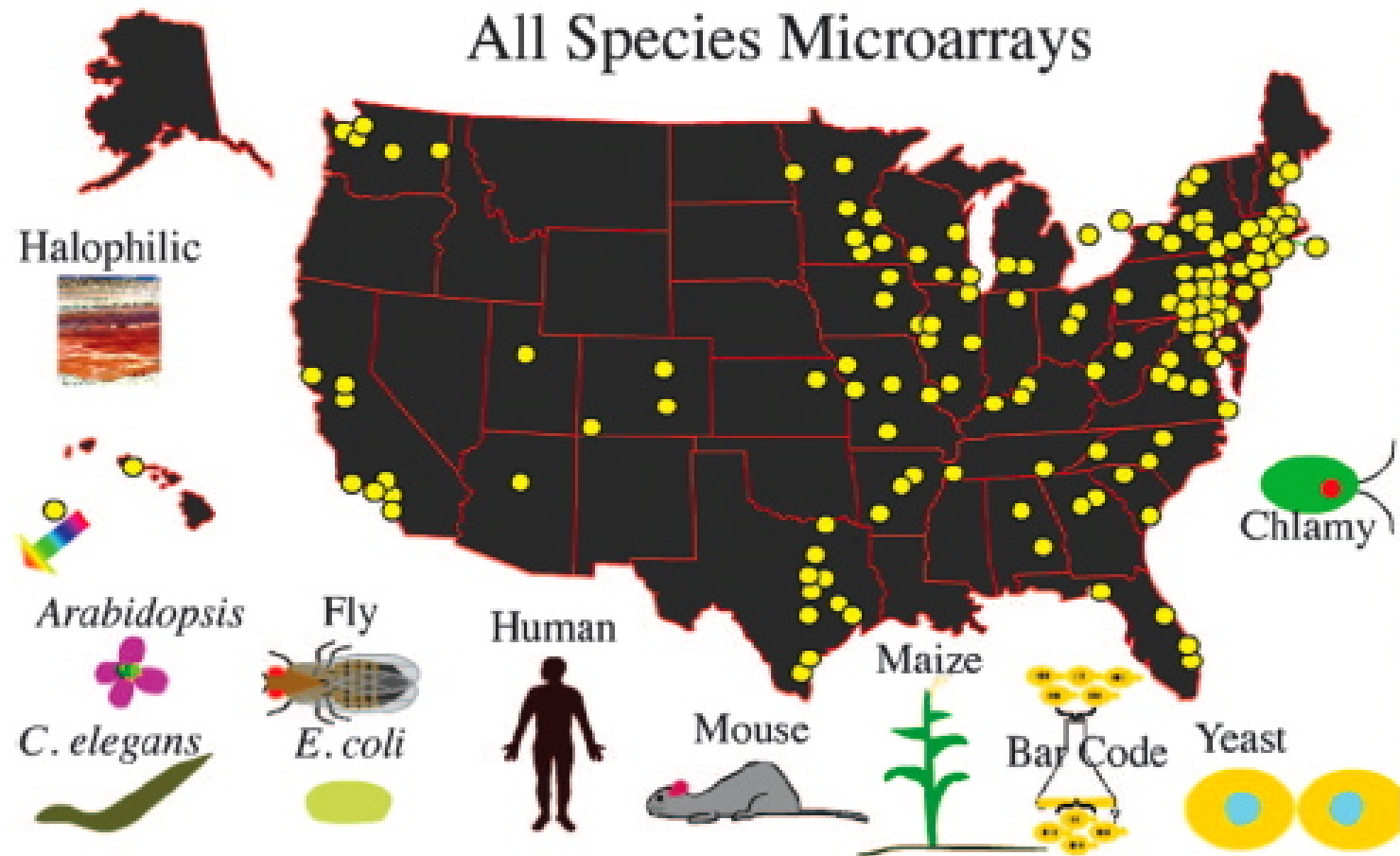


# Steady Growth Over Time



10,000<sup>+</sup> Undergraduates and Counting

# Distribution of GCAT Members





# GCAT Publication of Outcomes

EDUCATIONFORUM

COLLABORATIVE PROGRAMS

## Genome Consortium for Active Teaching (GCAT)

A. Malcolm Campbell,<sup>1,2,\*†</sup> Todd T. Eckdahl,<sup>2,4</sup> Edison Fowlks,<sup>2,5</sup> Laurie J. Heyer,<sup>2,3</sup>  
Laura L. Mays Hoopes,<sup>2,6</sup> Mary Lee Ledbetter,<sup>2,7</sup> Anne G. Rosenwald<sup>2,8</sup>

A supportive network of scientists and faculty brings sophisticated microarray experiments to the undergraduate lab and classroom.



## Basic Research Publications

2008: 4 peer-reviewed publications

2007: 2 peer-reviewed publications

2006: 1 peer-reviewed publication

# Student Learning Outcomes

Question	Topic	Increase (%)
1.	Microarray experimental error–dye bias	+ 36.2*
2.	Microarray experimental error–gradient	+ 10.5*
3.	Microarray negative controls	+ 10.3*
4.	Microarray experimental design	+ 38.2*
5.	Gene expression ratios using a graph	+ 5.8*
6.	Gene expression–probability	+ 0.2
7.	Gene expression–gene clusters	+ 22.3*
8.	Gene expression–regulatory cascade	+ 14.9*
9.	Gene expression–gene circuit graphs	+ 11.8*
10.	Interpreting microarray results	+ 19.0*
11.	Diagnosis with microarrays	+ 12.5*

\* indicates  $p < 0.05$ ;  $N = 409$

# Synthetic Biology Ergistic Math

## Synthetic Biology is

- A) the design and construction of new biological parts, devices, and systems, and
- B) the re-design of existing, natural biological systems for useful purposes.

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## What is synthetic biology?

- Synthetic biology refers to both:
  - the design and fabrication of biological components and systems that do not already exist in the natural world
  - the re-design and fabrication of existing biological systems.

## What is the difference between synthetic biology and systems biology?

- Systems biology studies complex biological systems as integrated wholes, using tools of modeling, simulation, and comparison to experiment. The focus tends to be on natural systems, often with some (at least long term) medical significance.
- Synthetic biology studies how to build artificial biological systems for engineering applications, using many of the same tools and experimental techniques. But the work is fundamentally an engineering application of biological science, rather than an attempt to do more science. The focus is often on ways of taking parts of natural biological systems, characterizing and simplifying them, and using them as a component of a highly unnatural, engineered, biological system.

# BioBrick Registry of Standard Parts



jump to part

navigation

- Main Page
- Browse Part Types
- iGEM 2007 Wiki
- Community portal
- Recent changes
- Recent part changes

resources

- User Accounts
- Add a Part
- Part Searches
- DNA Repositories
- Sequence Analysis
- Assembly Tool
- Help

search

Go Search

article discussion edit history

## Registry of Standard Biological Parts





■ Browse Parts by Type



■ iGEM 2007 Parts by Team



■ iGEM 2006 Parts by Team



■ iGEM 2007 Wiki



■ iGEM 2006 Wiki



■ Parts by Lab



Featured Parts



Help & Documentation



Users & Groups

### Registry Toolbox

-  Add a part
-  Search Parts  
More...
-  DNA Repositories
-  Sequence Analysis

### Registry Community

- **Participate in the Registry Logo Redesign contest! More info [HERE!](#)**
- For information about iGEM 2007, see [www.igem2007.com](http://www.igem2007.com)
- We have a new [tutorial for starting teams](#) in the [Help](#) section
- [iGEM 2007 team parts](#) have new [parts sandboxes](#) and [favorites](#) available
- We are starting an editorial board for promoting well-defined and useful parts to BioBrick™ part

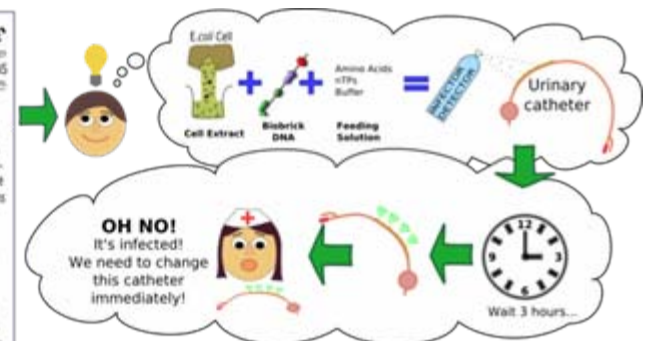
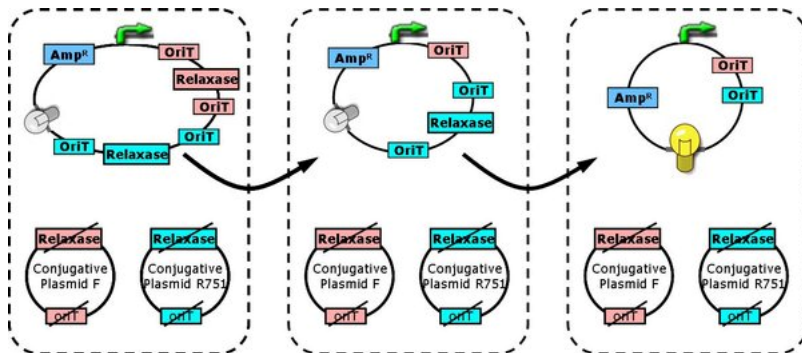


Send Parts to the Registry

[http://parts.mit.edu/registry/index.php/Main\\_Page](http://parts.mit.edu/registry/index.php/Main_Page)



# iGEM: international Genetically Engineered Machines



Peking University

Imperial College

# Student Success at iGEM






# Student Publication and Notoriety

**SCIENTIFIC AMERICAN**

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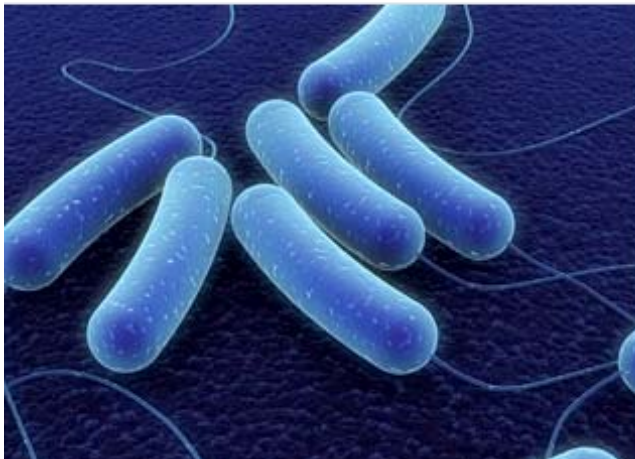
May 30, 2008

## DNA Computer Puts Microbes to Work as Number Crunchers

Study shows genetic material in bacteria can be harnessed to solve complex math problems

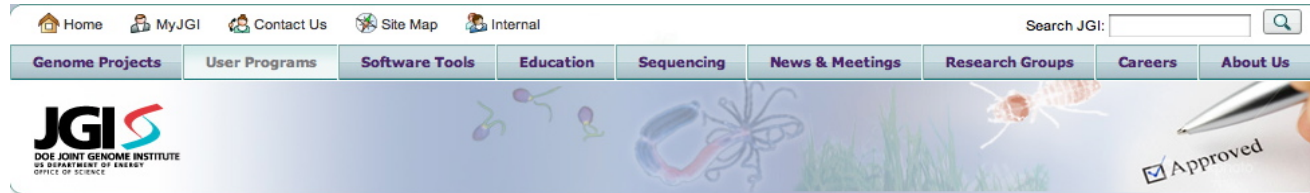
by Nikhil Swaminathan

SHARE 2 diggs   NT    6 points EMAIL PRINT TEXT SIZE: - +



It's not your normal, electronic silicon-based machine, but scientists have made a computer from a small, circular piece of DNA, then inserted it into a living bacterial cell and unleashed the microbe to solve a mathematical sorting problem.

"A computer is any system that can read some input and give some readable output," says Karmella Haynes, a biologist at Davidson College in North Carolina and co-author of a new study appearing in the [Journal of Biological Engineering](#). Haynes and her team looked to harness the power of DNA recombination to solve the so-called "burnt pancake problem": a puzzle about how to stack different-size flapjacks that are burned on one side and perfectly cooked on the other using the fewest number of flips



Genomics  
is the new  
molecular  
biology.

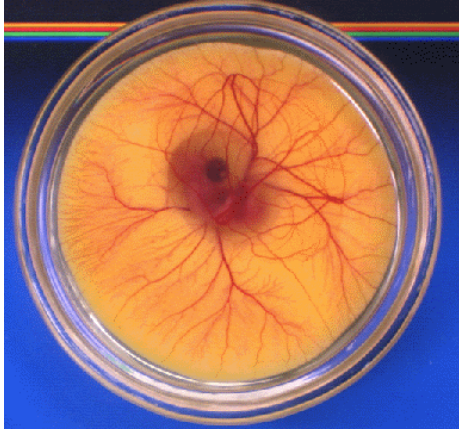


If a student seeks a research career, he or she had better pursue an education that enhances his or her quantitative skills.

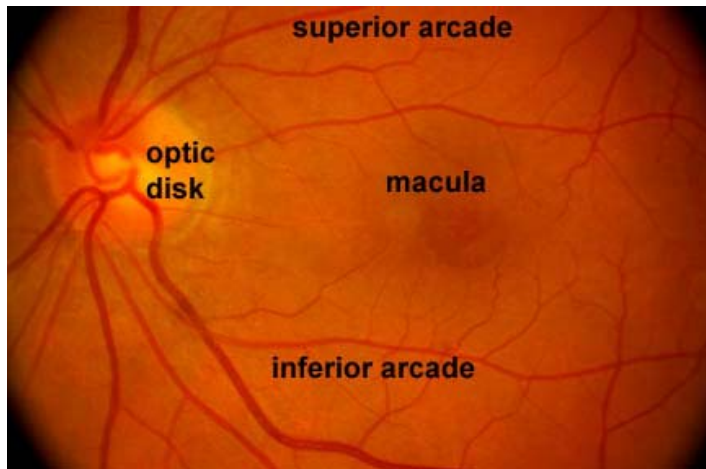


# Math is the New Microscope

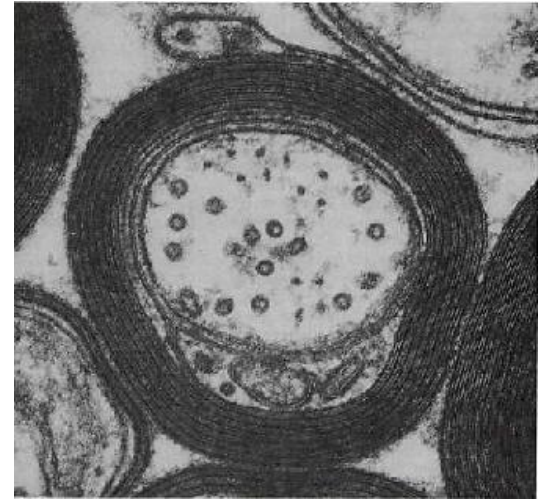
What is the optimum branching angle?



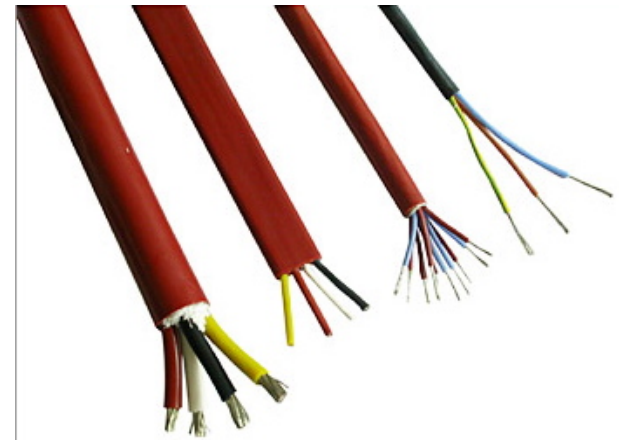
$$f(x) = k \left( \frac{x}{r_1^4} + \frac{\sqrt{(d-x)^2 + y^2}}{r_2^4} \right)$$



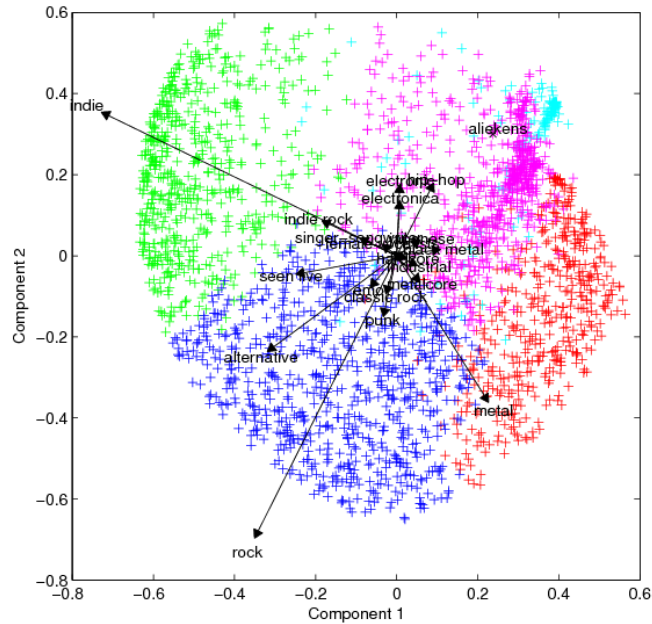
How much myelin is best?



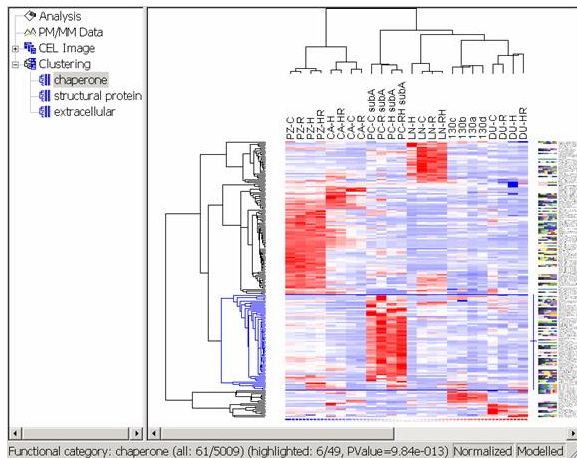
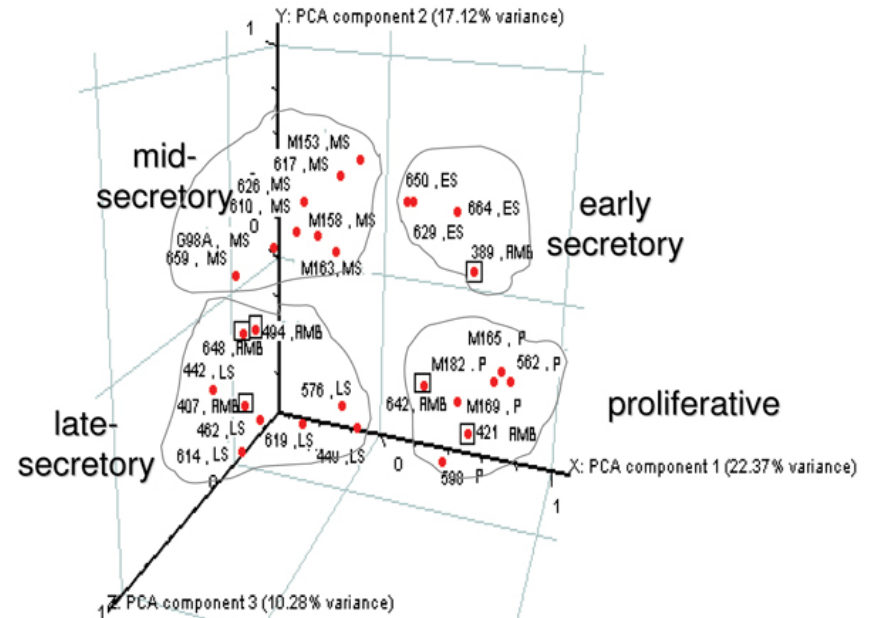
$$v = \alpha \left( \frac{r}{R} \right)^2 \ln \left( \frac{r}{R} \right)$$



# Clustering



# Principle Component Analysis



$$u[m] = \frac{1}{N} \sum_{n=1}^N X[m, n]$$

$$\mathbf{w}_1 = \arg \max_{\|\mathbf{w}\|=1} \text{var}\{\mathbf{w}^T \mathbf{x}\} = \arg \max_{\|\mathbf{w}\|=1} E\left\{(\mathbf{w}^T \mathbf{x})^2\right\}$$

Since our students' needs are changing,  
what must we do as their teachers to  
keep up with the changing demands?





How can we retool ourselves and our courses?

# Faculty Development - free & hands on.



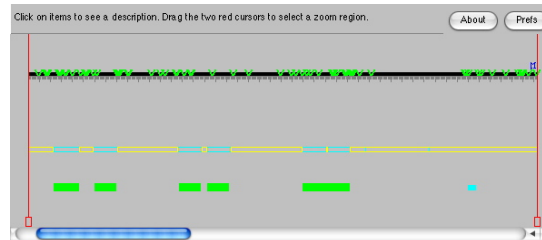


# How can we modify existing courses?

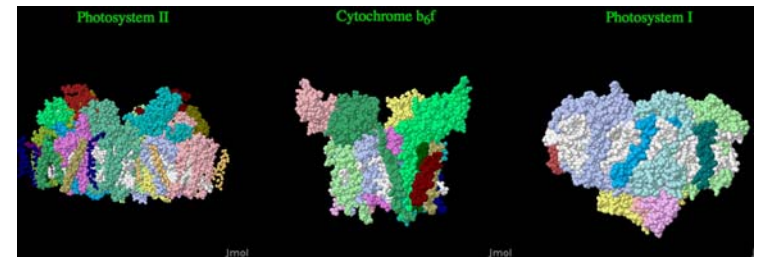
What is the probability of having HIV given a positive test?

$$P(\text{HIV}_{\text{pos}} \mid +) = \frac{P(+ \mid \text{HIV}_{\text{pos}}) P(\text{HIV}_{\text{pos}})}{P(+ \mid \text{HIV}_{\text{pos}}) P(\text{HIV}_{\text{pos}}) + P(+ \mid \text{HIV}_{\text{neg}}) P(\text{HIV}_{\text{neg}})}$$

What is the topology of the encoded protein?



What is the 3D shape of this protein?

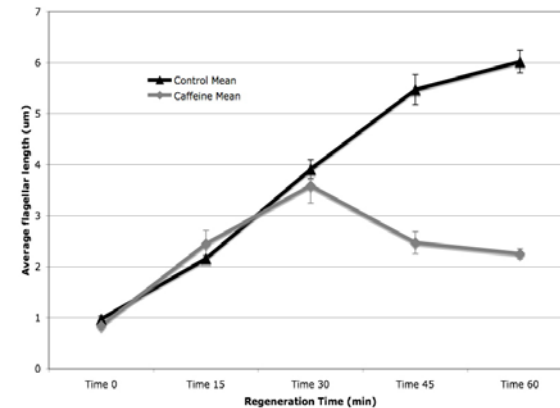
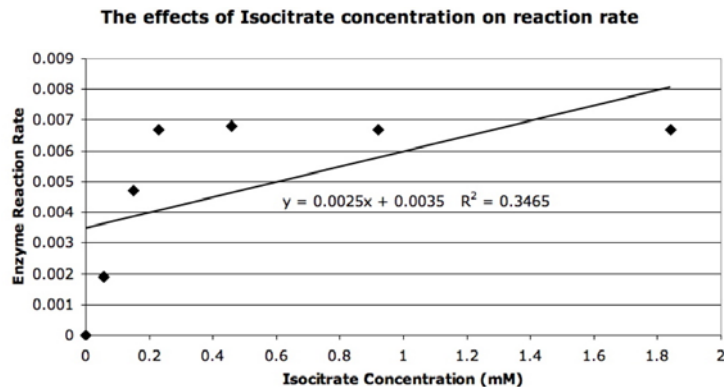
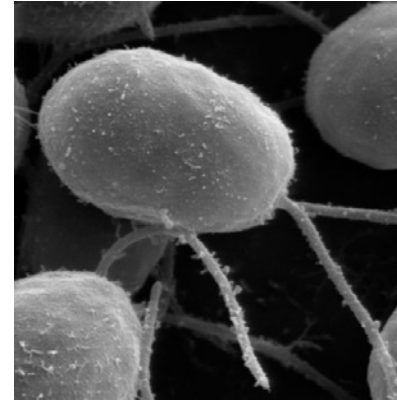
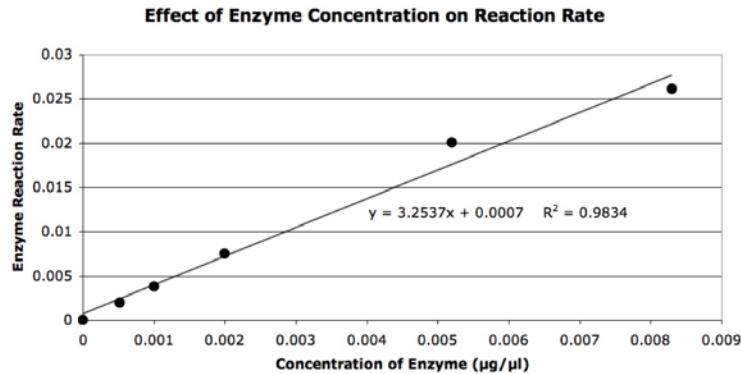


# Overhaul Introductory Biology

- ✓ Focus on 5 main concepts
- ✓ Use fewer examples
- ✓ Students construct their knowledge
- ✓ Provide data to support claims
- ✓ Connect content to what they know
- ✓ **Include math throughout**
- ✓ Incorporate ELSI throughout
- ✓ Dissolve false division of big and small biology
- ✓ Write in comfortable style



# Update labs. Include statistics and probability.



## Get CCLI funding from NSF

# Collaborate Wisely. Make Smart Hires.

E. Stevens (DC Chem)

D. Boye (DC Phys)

L. Heyer (DC Math)

V. Case (DC Bio)

D. Wessner (DC Bio)

J. Williamson (DC Bio)

D. Kimmel (DC Bio)

S. Sundby (Macalester Bio)

S. Tonidandel (DC Psych)

A. Ordman (Beloit Bio)

C. Paradise (DC Bio)

B. Lom (DC Bio)

B. Hatfield (DC Bio)

E. Fowlks (Hampton Bio)

A. Rosenwald (Georgetown Bio)

T. Eckdahl (MWSU Bio)

J. Poet (MWSU Math)

L. Hoopes (Pomona Bio)

M.L. Ledbetter (Holy Cross Bio)

V. Armbrust (UW Oceanography)

## Smart Heyer

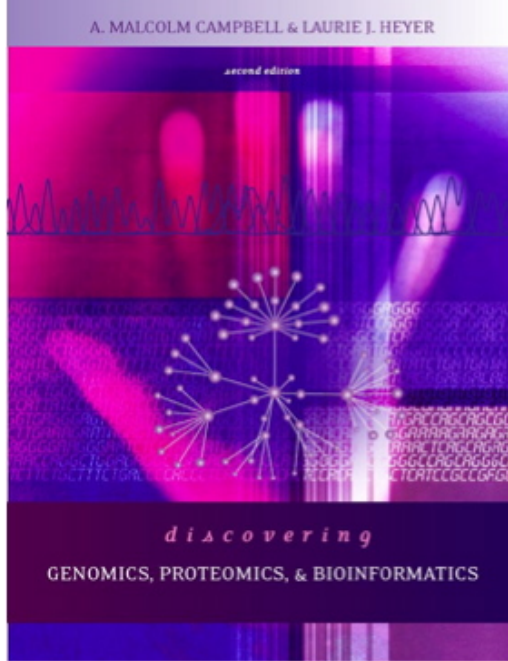
Students 2008



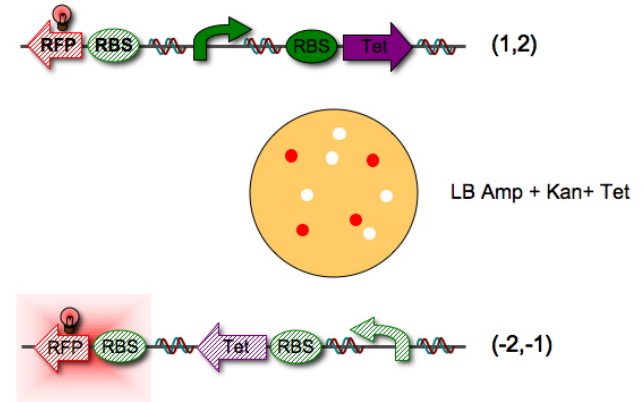
Students 2007



# Genomics

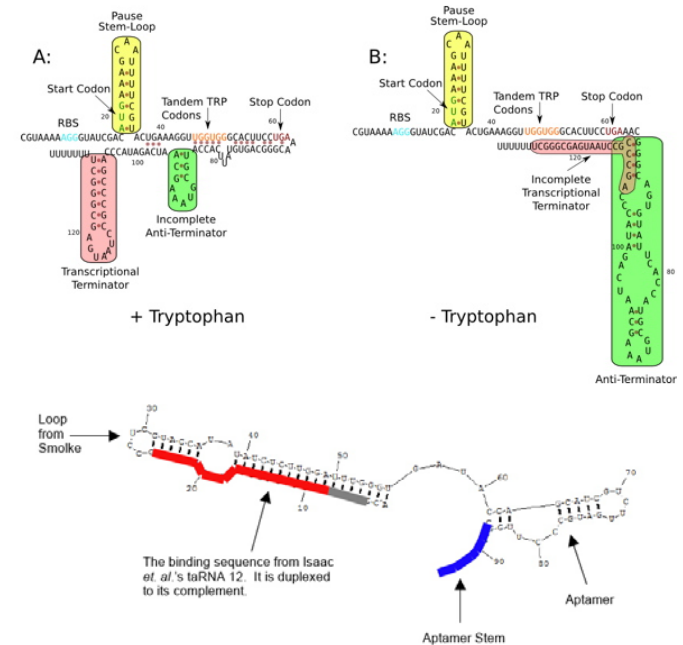
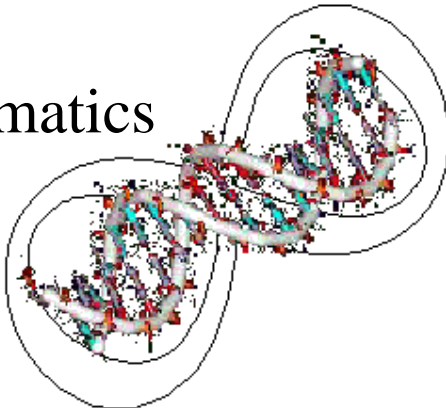


# Synthetic Biology



*Do we need new courses?*

# Bioinformatics





Real research  
is the curriculum.



**Interdisciplinary Training for Undergraduates in Biological  
and Mathematical Sciences (UBM)**

**PROGRAM SOLICITATION**

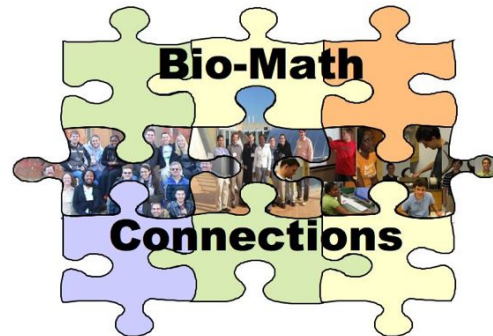
NSF 06-541

REPLACES DOCUMENT NSF 04-546



National Science Foundation  
Directorate for Biological Sciences  
Emerging Frontiers  
Directorate for Education and Human Resources  
Division of Undergraduate Education  
Directorate for Mathematical and Physical Sciences  
Division of Mathematical Sciences  
Office of Multidisciplinary Activities

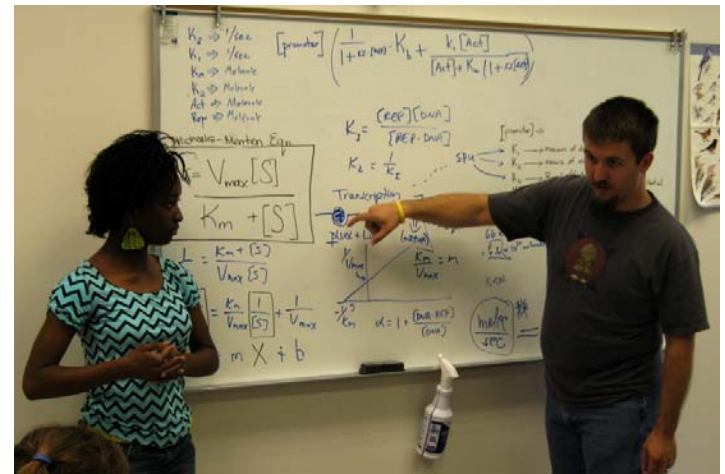
Why do we  
reward  
memorization is  
our classes?



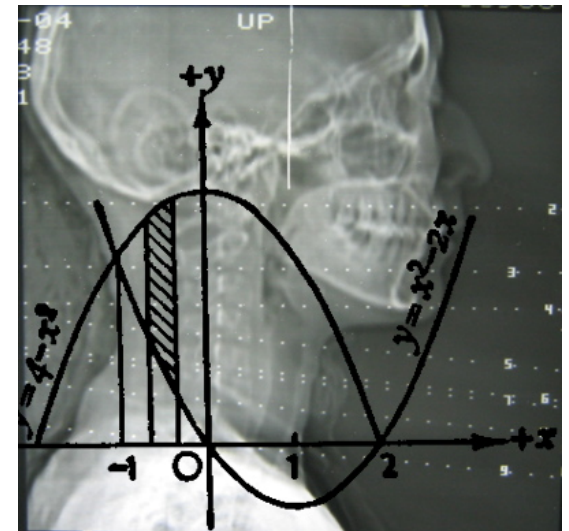


At Davidson, I have taught the following classes:

- MAT 130 Calculus I
- [MAT 130 M Calculus & Modeling I](#)
- [MAT 137 Calculus & Modeling II](#)
- MAT 135 Calculus II
- MAT 150 Linear Algebra
- MAT 210 Mathematical Modeling
- MAT 235 Differential Equations
- MAT 340 Probability
- MAT 341 Mathematical Statistics
- MAT 482 Introduction to Operations Research
- [BIO / CSC 310 Bioinformatics](#)



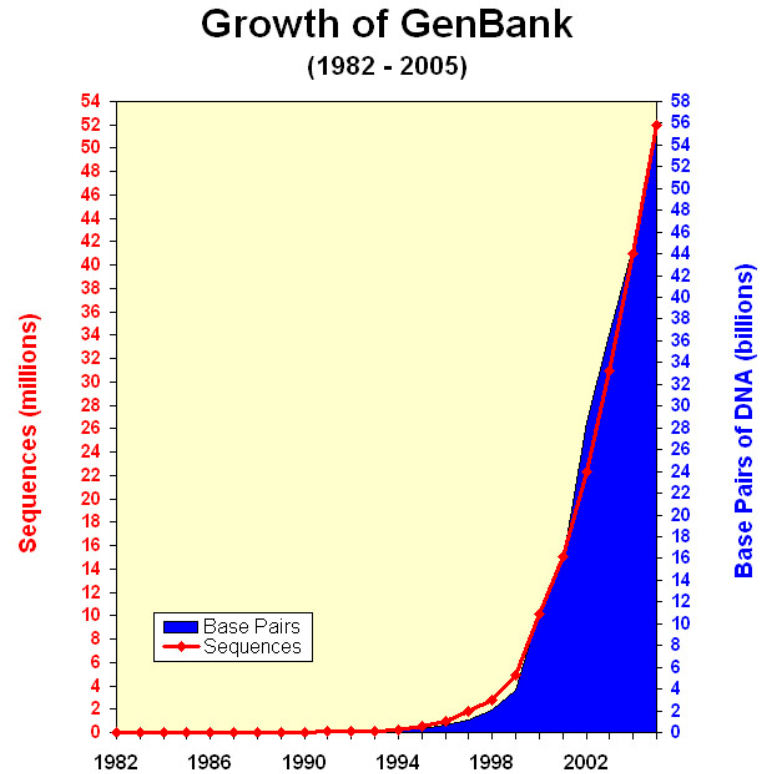
*Should we team teach more?*





# Is more content better?

How much do your students remember now?



Neil Campbell's *Biology* 5th Edition 55 chapters, 1290 pages  
Neil Campbell's *Biology* 6th Edition 55 chapters, 1175 pages  
Neil Campbell's *Biology* 7th Edition 55 chapters, 1312 pages  
Neil Campbell's *Biology* 8th Edition 55 chapters, 1393 pages

**MAAIKE** f Dutch  
Dutch diminutive of **MARIA**

**MAARIA** f Finnish  
Finnish form of **MARIA**

**MAARIKA** f Finnish, Estonian  
Diminutive of **MAARIA** (Finnish) or **MAARJA** (Estonian).

**MAARIT** f Finnish  
Finnish form of **MARGARET**

**MAARJA** f Estonian  
Estonian form of **MARIA**

**MAARTEN** m Dutch  
Dutch form of **MARTIN**

**MAARTJE** f Dutch  
Dutch feminine form of **MARTIN**

**MAAS** m Dutch  
Dutch short form of **THOMAS**

**MAATA** f Maori  
Maori form of **MARTHA**

**MAAYAN** f Jewish  
Means "spring of water" in Hebrew.

**MABEL** f English  
Medieval form of **AMABEL**... [\[more\]](#)

**MABELLA** f English (Rare)  
Elaborated form of **MABEL**

**MABELLE** f English  
Variant of **MABEL**... [\[more\]](#)

**MABLE** f English  
Variant of **MABEL**

**MABON** m Welsh, Welsh Mythology  
Derived from Welsh *mab* meaning "son"... [\[more\]](#)

**MABYN** f Welsh  
Means "youth" in Welsh... [\[more\]](#)

How would you respond if I gave you a list of 500 student names and required you to memorize them?

**MAB**

**MABEL**

**MABLI**

**MABON**

**MABYN**

**MAC**

**MACADRIAN**

**MACARENA**

**MACARIA**

**MACARIO**

**MACAWI**

**MACAYLE**

**MACBETH**

**MACE**

**MACEO**

**MACHA**

**MACHIKO**

**MACKENZIE**

**MACON**

**MACONAQUEA**

**MACY**

**MACYN**

**MADA**

**MADAN**

**MADDEN**

**MADDOCK**

**MADDOX**

**MADDY**

**MADELEINE**

**MADELIA**

**MADELINA**

**MADELINE**

**MADELYN**

**MADGE**

**MADISON**

**MADLAINA**

**MADOG**

**MADONNA**

**MADRA**

**MADRID**

**MADRONA**

**MAE**

**MAEGAN**

**MAEKO**

**MAEL**

# The Star Fleet Academy Myth



Our students can learn more each year.





Can we tweak what we have  
and honestly meet the needs  
of our students?



If we currently cover all the important stuff....



...how can we add more content?



# Base Your Teaching on Data

Triage based on educational goals!

- 1) List goals
- 2) What could students do if goals are met?
- 3) Measure if students can do #2



This presentation has offered  
some answers and now I invite  
you to an honest discussion.

Can I teach outside my area?

How do I cover more material?

Am I equally trained in math and biology?

Do I want students to be equally trained in both?

What happens if my students are smarter than me?!



# Learning is the Primary Goal

