Positive Feedback Between Synthetic Biology and Natural Learning

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Biology Department and GCAT

University of Alaska - Fairbanks
March 2, 2012
Outline of Presentation

1. Introduce synthetic biology
2. Applications of synthetic biology
3. Synthetic biology research at Davidson College
4. Why make biological computers?
5. How do we prepare undergraduates for research?
What is Synthetic Biology?

Implementation of engineering principles and mathematical modeling to the design and construction of biological parts, devices, and systems with applications in energy, medicine, and technology.

www.bio.davidson.edu/projects/gcat/Synthetic/What_Is_SynBio.html
Synthetic Biology: Win-Win

Win #1: your design functions as expected.
Synthetic Biology: Win-Win Research

Win #1: your design functions as expected.

Win #2: your design fails but you uncover basic biology
Real World Applications
of
Synthetic Biology
Synthetic Biology
Land Mine Detection

New weed may flag land mines

By John K. Borchardt | Contributor to The Christian Science Monitor
Production of Medicines

$1 per pill
Production of Medicines

10¢ per pill
Biofuels from Algae

CO$_2$-neutral

1,000,000 gallons in 2008
Synthetic Biology
at
Davidson College

Laurie Heyer, Todd Eckdahl & Jeff Poet

Building Bacterial Computers
Advantages of Bacterial Computation

Software  →  Hardware  →  Computation

http://www.dramnd.med.usyd.edu.au/

http://www.turbosquid.com
Advantages of Biological Computers

go anywhere - arctic, thermal vents, inside organisms

no electricity

self-replicating

no immune rejection
Self-replicating Computers

**Advantages of Bacterial Computation**

- **Self-replicating Computers**
- **Advantages**
  - Non-Polynomial (NP)
  - No Efficient Algorithms

**Diagrams**

- **Possible Paths through the Graph**
  - Number of Edges in the Graph

- **# of Processors**
  - Cell Division
Two Undergraduate Research Projects
Define the SATisfiability Problem

\[(G \text{ or } B) \& (G \text{ or } b) \& (G \text{ or } r) \& (g \text{ or } R)\]

\[G, \ g, \ B, \ b, \ R, \ r\]
Define the SATisfiability Problem

\[(G \lor B) \land (G \lor b) \land (G \lor r) \land (g \lor R)\]
Define the SATisfiability Problem

<table>
<thead>
<tr>
<th>B</th>
<th>b</th>
<th>G</th>
<th>g</th>
<th>R</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>B</td>
<td>R</td>
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<td>g</td>
<td>B</td>
<td>R</td>
<td></td>
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</tr>
</tbody>
</table>
Define the SATisfiability Problem

<table>
<thead>
<tr>
<th>Keys</th>
<th>4 open doors</th>
<th>3 open doors</th>
<th>2 open doors</th>
</tr>
</thead>
<tbody>
<tr>
<td>B b G g R r</td>
<td>GorB</td>
<td>Gorb</td>
<td>gorR</td>
</tr>
<tr>
<td>G B R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G B r</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g B R</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Converting Math to Biology
Central Dogma

DNA
atgcctactcactacctatatagcgcat

\[ \downarrow \]

transcription

mRNA
\textbf{aug} ccc uac uca cua ccu aua ccg cau

\[ \downarrow \]

translation

Protein
\textbf{M P Y S H P I P H}

\text{Sunday, March 4, 2012}
Frameshift Mutation

DNA
atgcctactcactacctatagcgc

mRNA
\textcolor{green}{aug ccc uac uca cua ccu auu ccg cau} \quad \textcolor{red}{aug ccc Cuu acu cac uac cua uac gcg au}

Protein
\textcolor{green}{MPYSHPIPH} \quad \textcolor{red}{MPS\textcolor{red}{THYHR}}
Frameshift Suppression

DNA
atgcctactcactacctatagcgcat

DNA
atgcctactcactacctatagcgcat

mRNA
aug ccc uac uca cuu ccu auu ccg cau

5 base suppressor tRNA
aug cccUC uac uca cuu ccu auu ccg cau

Protein
MPYSHPIPH

Protein
M S YSHPIPH
Suppressor tRNA

core tRNA nucleotides

serine

5 base anticodon

G A G G G
Coding 2-SAT Clause

G

ATG NNNNN gNN NNN

satisfied
Coding 2-SAT Clause

G

ATG NNNNN gNN NNN  →  satisfied

OR

B

ATG NNN NNg NNNNN  →  satisfied

ATG NNN NNg NNN  →  no satisfaction
Positive Feedback Amplification

Diagram:
- T.T. pLux
- RBS
- FSL-LuxI
- RFP
- T.T. pLac
- LuxR
- T.T.

5mer
Positive Feedback Amplification
Positive Feedback Amplification

Diagram:

- T.T. pLux
- RBS
- FSL-LuxI
- RFP
- T.T. pLac
- LuxR
- T.T.

5mer
Positive Feedback Amplification


5mer

3OC6
Positive Feedback Amplification


5mer

3OC6
Positive Feedback Amplification
Positive Feedback Amplification
Results

no RFP
- control

wt RFP
+ control

[Images of two test tubes, one with a yellow substance labeled "no RFP - control" and another with a red substance labeled "wt RFP + control"]
Results

no RFP - control
frame shift “leak”

wt RFP + control
Results

- no RFP (control)
- frame shift “leak”
- +tRNA CGGUC
- +tRNA CCACU
- wt RFP + control
Results v2.0

GFP/ cell density

- no frame shift
- 2 SAT 1 clause
- 2 SAT 2 clause
- no frame shift

+ 3 tRNAs

Sunday, March 4, 2012
Can we build a bacterial cryptographic hash function?
What is a hash function?
Can Bacteria Perform a Hash Function?
Use XOR Logic Gate for Hash Function

<table>
<thead>
<tr>
<th>Input 1</th>
<th>Input 2</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
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</tbody>
</table>
Use XOR Logic Gate for Hash Function

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</tr>
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</tbody>
</table>

![XOR Logic Gate Diagram]
Use XOR Logic Gate for Hash Function

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</tr>
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<td>1</td>
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<td>0</td>
</tr>
</tbody>
</table>

![XOR Logic Gate Diagram]
Design Linear Bacterial Hash Function

\[ \text{CAB} = 010000001 \]

\[ \text{HASH VALUE} = 0 \]
Time-Delayed Bacterial Growth

3 hours

15 hours

40 hours

Amp^R

β-lactamase

β-lactamase

β-lactamase
Time-Delayed Bacterial Growth

0 hours

1 mm
DNA-based XOR Logic Gate
DNA-based XOR Logic Gate

3OC6 (Input B)

pLux

pOmpC

RBS

RFP
DNA-based XOR Logic Gate

High Osmolarity (Input A)

pOmpC

pLux

RBS

GFP
DNA-based XOR Logic Gate

High Osmolarity (Input A)

3OC6 (Input B)

<table>
<thead>
<tr>
<th>High Osmolarity (Input A)</th>
<th>3OC6 (Input B)</th>
<th>Fluorescence (Output)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1 (GFP)</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1 (RFP)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
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</tbody>
</table>
Testing Bacterial XOR Logic Gate

<table>
<thead>
<tr>
<th></th>
<th>LB</th>
<th>3OC6</th>
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</thead>
<tbody>
<tr>
<td>Input A</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Input B</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Output</td>
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Relative Fluorescence

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</tbody>
</table>

XOR +LuxR

RFP

GFP
Testing Bacterial XOR Logic Gate

<table>
<thead>
<tr>
<th></th>
<th>RFP</th>
<th>GFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB</td>
<td>-</td>
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<tr>
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<td>-</td>
<td>+</td>
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</table>

Relative Fluorescence

XOR +LuxR

RFP

GFP

High Osmolarity (Input A)

3OC6 (Input B)

pOmpC

pLux

RBS

GFP

RFP
Testing Bacterial XOR Logic Gate

Relative Fluorescence

XOR +LuxR

RFP
GFP

RFP
GFP
0

<table>
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Testing Bacterial XOR Logic Gate

Relative Fluorescence

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XOR +LuxR

High Osmolarity (Input A)
3OC6 (Input B)
Why did XOR Gate Fail?

<table>
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<td>+</td>
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Why did XOR Gate Fail?

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<td>+</td>
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</tbody>
</table>

Relative Fluorescence

0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00

XOR no LuxR

RFP
GFP

Sunday, March 4, 2012
Why did XOR Gate Fail?

<table>
<thead>
<tr>
<th>Condition</th>
<th>RFP</th>
<th>GFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3OC6</td>
<td>-</td>
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</table>

Relative Fluorescence

0
Why did XOR Gate Fail?

<table>
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</tr>
<tr>
<td>GFP</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

Relative Fluorescence

0 0

XOR no LuxR

RFP

GFP

Sunday, March 4, 2012
Why did XOR Gate Fail?

![Graph showing relative fluorescence levels for XOR no LuxR, indicating 0 RFP and 0 GFP, with a significant increase in GFP when 3OC6 is present.]
Why did XOR Gate Fail?

### Graph Description
- **Y-axis:** Relative Fluorescence
- **X-axis:** Conditions
- **Legend:**
  - Red: RFP
  - Green: GFP
- **Conditions:**
  - XOR no LuxR
  - 00
  - GFP

### Table
<table>
<thead>
<tr>
<th></th>
<th>LB</th>
<th>3OC6</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFP</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>GFP</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

### Diagram Elements
- High Osmolarity (Input A)
- 3OC6 (Input B)
- RBS
- pOmpC
- pLux
- GFP
pLux + LuxR Promotes Backwards

<table>
<thead>
<tr>
<th></th>
<th>LuxR</th>
<th>30C6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>+</td>
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</tbody>
</table>

Relative Fluorescence

- LuxR
- 30C6

Sunday, March 4, 2012
pLux + LuxR Promotes Backwards

Relative Fluorescence

<table>
<thead>
<tr>
<th></th>
<th>LuxR</th>
<th>3OC6</th>
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<tbody>
<tr>
<td>pLux</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>pLux + LuxR</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>pLux + RFP</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>pLux + RBS</td>
<td>+</td>
<td>+</td>
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</table>

Sunday, March 4, 2012
pLux + LuxR Promotes Backwards

<table>
<thead>
<tr>
<th></th>
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<th>3OC6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Fluorescence</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
</tbody>
</table>
pLux + LuxR Promotes Backwards

Relative Fluorescence

+LuxR

RFP

RBS

pLux

<table>
<thead>
<tr>
<th>LuxR</th>
<th>-</th>
<th>-</th>
<th>+</th>
<th>+</th>
</tr>
</thead>
<tbody>
<tr>
<td>3OC6</td>
<td>-</td>
<td>+</td>
<td></td>
<td></td>
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</tbody>
</table>
### pLux + LuxR Promotes Backwards

**Graph:**
- **Y-axis:** Relative Fluorescence
- **X-axis:** Various conditions
- **Legend:**
  - RFP
  - RBS
  - pLux

**Table:**

<table>
<thead>
<tr>
<th></th>
<th>LuxR</th>
<th>3OC6</th>
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<tbody>
<tr>
<td><strong>-</strong> LuxR</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>+</strong> LuxR</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><strong>-</strong> 3OC6</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><strong>+</strong> 3OC6</td>
<td>-</td>
<td>+</td>
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</table>

**Significance:**
- The presence of LuxR promotes a higher relative fluorescence, suggesting a forwards regulatory effect.
- The presence of 3OC6 with LuxR shows a higher fluorescence compared to LuxR alone, indicating an interaction effect.

**Note:**
- This graph illustrates the effect of LuxR and 3OC6 on relative fluorescence, with LuxR promoting fluorescence in the presence of 3OC6.
Why build bacterial computers?
Evolution of Computers

1943
Evolution of Computers

iPhone in 2012
Evolution of Bacterial Computers

$E. \text{coli}$ in 2012

Living Hardware in 2022
How do we clone DNA?
Can we do this for intro bio??
BioBricks

BioBrick Part

BioBrick plasmid backbone + 1 part

origin

antibiotic resistance

(http://partsregistry.org/Plasmids)
BioBricks

BioBrick plasmid backbone + 1 part

Eco RI  Xba I  Spe I  Pst I

(origin) → antibiotic resistance

(http://partsregistry.org/Plasmids)
BioBricks

BioBrick plasmid backbone + 1 part

identical sticky ends

Eco RI
Pst I

Xba I
Spe I

(http://partsregistry.org/Plasmids)
BioBricks

put B downstream of A

Part A

origin

antibiotic resistance

Part B

origin

antibiotic resistance
BioBricks

gel purify

Part A

origin

antibiotic resistance

Part B

gel purify
BioBricks

ligate

Part A

Part B

origin

antibiotic resistance
Biobricks

mixed site = scar

E  X  Part A  M  Part B  S  P

origin  antibiotic resistance

transform
Challenge:

put A upstream of B
Details of Cloning

Part A
- Origin
- Antibiotic resistance

Part B
- Origin
- Antibiotic resistance

Diagram showing the flow of genetic material from Part A to Part B with the origin and antibiotic resistance genes highlighted.
Gel Purification

Part B

origin

antibiotic resistance
Gel Purification

origin - antibiotic resistance

Part B

Sunday, March 4, 2012
Gel Purification
Part A

origin

antibiotic resistance

Part B

Gel Purification
Gel Purification

Part A

origin

antibiotic resistance

Part B
Part A

origin

antibiotic resistance

Gel Purification

Part B

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Gel Purification

Part A

Part B

origin

antibiotic resistance

E X S P

S P

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Ligation

Part A

Part B

origin

antibiotic resistance
Can intro bio students do real synthetic biology research in 3 hour labs?
Golden Gate Assembly Method

- **TT + RBS + RFP**
- **TT**
- **RBS**
- **RFP**
- **origin**
- **antibiotic resistance**
- **plasmid backbone**

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Golden Gate Assembly Method

promoter + RBS + RFP

RBS

RFP

origin

antibiotic resistance

plasmid backbone
Eco RI

GAATTC
CTTAAG

palindrome

type II
Eco RI

GAATTC
CTTAAG

palindrome

type II
Eco RI

GAATTC
CTTAAG

type II
Eco RI

G
CTTAA

AATTC
G

type II
Bsa I

GAGACC
CTCTTG

not a palindrome

type IIIs
Bsa I

1234nGAGACC
-----nCTCTGG

type IIIs
Bsa I

d1234nGAGACC
nCTCTTG

type IIIs
Bsa I

GGTCTCn

CCAGAGn1234

type IIIs
Bsa I

GGTCTCn
CCAGAGn1234

---

type IIIs
Bsa I

1234 nGAGACC
----- nCTCTGG

GGTCTCTCn-----
CCAGAGAn1234

cuts left
cuts right

cuts right
TT + RBS + RFP
CGAC\textsuperscript{t}GAGACC$^{(TT)}$GGTCTCa
\textsuperscript{a}CTCTGG$^{(TT)}$CCAGAG\textsuperscript{t}CGCC

RBS + RFP

RBS  

RFP

GCGG

GCTG
CGACTGAGACC(TT)GGTCTCaGCGG
GCTGaCTCTGG(TT)CCAGAGtCGCC
CGACtGAGACC (TT) GGTCTCa
aCTCTGG (TT) CCAGAGtCGCC

CGAC (promoter)
(promoter) CGCC

RBS + RFP

RBS  RFP
CGAC\textit{tGAGACC} (TT) GGTCTCa
\textit{aCTCTGG} (TT) \textit{CCAGAG}\textit{tCGCC}

\begin{align*}
\text{CGAC (promoter)} & \text{ GCGG} \\
\text{GCTG (promoter)} & \text{ CGCC}
\end{align*}

promoter + RBS + RFP
GGA Ligation Method

TT + RBS + RFP

TT

RBS

RFP

BsaI + Ligase

origin

antibiotic resistance

plasmid backbone
GGA Ligation Method

promoter + RBS + RFP

RBS

RFP

BsaI + Ligase

origin

antibiotic resistance

plasmid backbone

TT
GGA Ligation Method

promoter + RBS + RFP

no gel purifications!

originantiobiotic resistance

plasmid backbone
GGA Ligation Method

no gel purifications!

Origin antibiotic resistance plasmid backbone
## Campbell M Lab Parts

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Type</th>
<th>Description</th>
<th>Designer</th>
<th>Length</th>
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<tbody>
<tr>
<td>Blu_110000</td>
<td>Coding</td>
<td>Cre with Bsp recombination site and 1-Classes 2-SAT Promoter inserted</td>
<td>Eric Sawyer</td>
<td>10950</td>
</tr>
<tr>
<td>Blu_110001</td>
<td>Composite</td>
<td>dTomRBS:Cre2xSAT:Clustering:ppRNA COAG</td>
<td>Eric Sawyer</td>
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Sunday, March 4, 2012
dnakP1 promoter: Heat shock inducible

dnakP1 is naturally off, but is induced when E. coli is heat shocked, resulting in transcription downstream from this promoter.

Sequence and Features

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<th>Ruler</th>
<th>SS</th>
<th>DS</th>
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<th>Context: Part only</th>
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Assembly Compatibility: 10 12 21 23 25
Part: BBa_J100033: Experience
Designed by Chris Peak Group: Campbell, M., Lab (2011-09-01)

This experience page is provided so that any user may enter their experience using this part.
Please enter how you used this part and how it worked out.

Applications of BBa_J100033

Mean Fluorescence per Cell Density

- **A**: Experimental conditions

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<th>Condition</th>
<th>Mean Fluorescent Intensity (MFU/Cell)</th>
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<td>kPA1 (+)</td>
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</tr>
<tr>
<td>J10028 (-)</td>
<td>4000</td>
</tr>
<tr>
<td>pTet (+)</td>
<td>8000</td>
</tr>
<tr>
<td>pLac + IPTG</td>
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</tr>
<tr>
<td>pLac - IPTG</td>
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* p < 0.01

Cells containing dnaK1 without heat shock (incubated at 37°C) B: Experimental: cells containing dnaK1 with heat shock (incubated at 40°C) C: Negative control: part (J10028) without nTet repressor D: Positive control: part (J10028) with nTet repressor (always on) E: nLac promoter (always on) F: nLac promoter (PepT with inducer IPTG) G: nLac
Our Current Challenge: Introductory Biology

Integrating Concepts in Biology

by

A. Malcolm Campbell, Laurie J. Heyer and Christopher J. Paradise
What’s Wrong with Biology Education Now?

- Vocabulary is emphasized
- Experimental approaches are minimized
- Math is absent
- Memorization is rewarded
- Critical thinking is discouraged
- Information is irrelevant to students
If we currently cover all the important stuff....

...how can we add more content?
Too much content for the containers
Too much content for the containers
Start with the literature...
Present information and data...
... in the context of the big picture.
Artificial Divide within Biology

Small Biology

Big Biology
Five Levels of Organization

- Molecular
- Cellular
- Organismal
- Population
- Ecological System
Five Big Ideas of Biology

- Homeostasis
- Information
- Emergent Properties
- Evolution
- Cells

Biology

Sunday, March 4, 2012
Five by Five Matrix of Biology

- Information
- Homeostasis
- Emergent Properties
- Cells
- Evolution

- Molecular
- Ecological System
- Population
- Organismal
- Cellular

Biology
Five by Five Matrix of Biology

Information

Biology

Emergent Properties

Cells

Evolution

Population

Organismal

Molecular

Ecological System

Cellular

Homeostasis

Molecular

Ecological System

Organismal

Population

Cellular

Molecular

Ecological System

Organismal

Population

Cellular

Molecular

Ecological System

Organismal

Population

Cellular

Molecular

Ecological System
Five by Five Matrix of Biology

Information

Homeostasis

Ecological System

Evolution

Populations

Molecular

Organismal

Cellular

Information

Biology

Emergent Properties

Cells

Ecological System

Information

Biology

Emergent Properties

Cells

Ecological System

Information

Biology

Emergent Properties

Cells

Ecological System
Five by Five Matrix of Biology

- **Homeostasis**
  - Molecular
  - Ecological System

- **Emergent Properties**
  - Population
  - Organismal

- **Information**
  - Population
  - Ecological System

- **Evolution**
  - Population
  - Organismal

- **Cells**
  - Population
  - Ecological System

- **Biology**
  - Molecular
  - Ecological System

- **Ecological System**
  - Cellular
  - Organismal

Sunday, March 4, 2012
BioMath Explorations

BioMath Exploration 6.3

How can you fit exponential curves to data?

![Graph showing exponential curves](image-url)
Ethical, Legal and Social Implications

Are religion and evolution compatible?

Is science possible if you are uncertain about what is true?

Does basic biology have any impact on the real world?

Who owns your DNA?
Did my students learn less content?
Student Content Assessment

83% response rate (new)  
63% response rate (traditional)  

$p = 0.06$

percent correct

Fall 2010

$p = 0.97$

new

traditional

+/- SEM
Student Content Assessment

83% response rate (new)
63% response rate (traditional)

Fall 2010
Spring 2011

percent correct

$p = 0.97$
$p = 0.06$

new
traditional

 +/- SEM
Can my students analyze data better?
Student Skills Assessment

% Correct

Traditional

New

$p = 0.043$
Student Skills Assessment

- Traditional (quiz averages)
- New (quiz averages)

Percent Correct

Quiz

First
Second
Third
Fourth

new, $p = 0.015$

traditional, $p = 0.320$
Why bother changing?
National Recognition of Need to Change

VISION AND CHANGE
A CALL TO ACTION

A SUMMARY OF RECOMMENDATIONS
MADE AT A NATIONAL CONFERENCE ORGANIZED BY THE
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE
AP Biology is Changing to Match Our Design

AP® BIOLOGY
Curriculum Framework
2012–2013
Faculty: Laurie Heyer, Jeff Poet, Todd Eckdahl, Karmella Haynes, Pat Sellers, Mark Barsoum


The Duke Endowment, NSF, HHMI
Genome Consortium for Active Teaching (GCAT)
Davidson College James G. Martin Genomics Program
MWSU SGA, Foundation & Summer Research Institute
How is Synthetic Biology Different?

Abstraction

Modularity

Standards

Designing and modeling
How is Synthetic Biology Different?

Abstraction

Modularity

Standards

Designing and modeling

AND Logic Gate
How is Synthetic Biology Different?

Abstraction

Modularity

Standards

Designing and modeling

BioBrick Ends and Ligation
How is Synthetic Biology Different?

Abstraction
Modularity
Standards
Designing and modeling

Sunday, March 4, 2012
Increased Student Diversity

56 undergraduates in 7 years

<table>
<thead>
<tr>
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<th>Hispanic</th>
<th>First Generation</th>
<th>Asian Minority</th>
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campus: 74% Caucasian  
biology majors: 87% Caucasian
GCAT Faculty Workshop
Synthetic Biology

15 pairs of faculty
1 Bio + 1 Other
NSF & HHMI
What did my students think about this approach to intro bio?
“The method of learning, placing emphasis on the interpretation of data, has helped me not only in this class, but also in others.”

anonymous student course evaluation, Dec. 2010
“I found it much more beneficial using this approach compared to straight memorization. It allowed me to gain interpretation skills I was lacking before.”

anonymous student course evaluation, Dec. 2010
“The data-driven approach is brilliant. It alleviates the issues that I’ve always had of asking, ‘How do we know that? What’s the supporting data?’ ”
“Emphasis on big picture and understanding how to pull information from real data was an easier and more beneficial format than memorization of facts (which used to be a struggle for me).”
How did I test student learning?
Four Exams Per Semester

8 pts.

9) Limit your answers to a maximum of 2 sentences for each part.

a) Explain why it is adaptive for each eukaryotic organelle to be composed of a different lipid composition. Use data to support your answer.

Each one has a particular surface area to volume ratio and different lipids have different bending capacity. Rigid lipids produce larger volumes while relaxed lipids produce bends and small volumes inside membranes.

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<th>Rigid Membrane</th>
<th>Rigid Organelle</th>
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b) Would you predict that the secretory vesicles containing epinephrine would contain more rigid lipids, or flexible lipids? Use data to support your answer.

relaxed due to large surface area to volume ratio
Data Gallery for Answers
When did the students feel they were learning something different than in high school?
# Table of Contents

## Chapter 7 Evolution at the Cellular Level

7.1: How are new species formed? Discover how genomes can change dramatically to produce new species.

   * **BME 7.1**: What information is in a dot plot? Discover how to construct and interpret a dot plot for comparing whole genomes.

   * **ELSI 7.1**: Are GMOs safe?

7.2 Why doesn’t your stomach digest itself? Analyze experimental results showing that eukaryotes evolved a shared mechanism to retain proteins inside the endoplasmic reticulum.

   * **BME 7.2**: Cause or effect? Explore the meaning of correlation, and how it is quantified.

7.3 Why do my allergies get worse each year? Determine that B cells evolve in days to produce stronger immune responses.

   * **ELSI 7.2**: Banning PB&J: How far should a society go to protect the rights of an individual?

7.4 Why are corals dying around the world? Realize that species can coevolve as symbionts and become interdependent.

   * **BME 7.3**: Can you predict coral bleaching? Evaluate the fit and predictive ability of a trendline.
Table of Contents

Chapter 17 Emergent Properties at the Cellular Level

17.1 Do unicellular species have to work solo? **Realize that microbes use quorum-sensing, biofilms and communal behavior to enhance their functions.**

17.2 How can changes in two cells affect an entire plant? **Appreciate how guard cells change their shape to regulate plant gas exchange through stomata.**

*BME 17.1: Can local decisions have global effects? Model the opening of stomata using a simulation of local rules.*

17.3 How do brain cells store memories? **Discover how long-term memories are formed by analyzing classic experiments on Aplysia learning.**

*ELSI 17.1: If pills could make you remember or forget, would you take them?*

17.4 Does the genome allow random actions by cells? **Learn how random movements of molecules determine cell phenotypes which can be transmitted across generations.**

*BME 17.2: What is chaos?*
Chapter 22 Homeostasis at the Cellular Level

22.1 Why is paraquat used in America but illegal in Europe? Analyze classic experiments to deduce how light energy is captured by plant cells.

22.2 How does Brazil’s rainforest affect Greenland’s glaciers? Determine how carbon dioxide is fixed by photosynthetic cells into biological molecules.

ELSI 22.1: How do you compromise when a policy hurts one country but helps another?

22.3 Is there anywhere on earth devoid of life? Explore inhospitable niches where microbes have evolved homeostatic mechanisms to survive harsh conditions.
Student Skills Assessment

% Correct

- Traditional
- New

Quiz 1  Quiz 2  Quiz 3  Quiz 4

$p<0.01$

$p<0.05$