Integrating Teaching and Research: What would MacGyver Do?

A. Malcolm Campbell
Biology Department and GCAT

Enhancing Biological Science Research Opportunities at Primarily Undergraduate Institutions (PUIs)
CSU Fullerton
July 27, 2012
Outline of Presentation

Who is MacGyver? Was he a science major?

What have I learned about undergraduate research?

How have I changed my courses to facilitate research?

Did my lab course change too?

Can you join a community of PUI researchers?

Why didn’t I think of that? (real research example)
What would MacGyver Do?

http://www.youtube.com/watch?v=fPPOo2JIXtc
What would MacGyver Do?
What would MacGyver Do?
What would MacGyver Do?
What would MacGyver Do?
What would MacGyver Do?

Saturday, July 28, 2012
What would MacGyver Do?
What would MacGyver Do?

Saturday, July 28, 2012
What would MacGyver Do?
What would MacGyver Do?
What would MacGyver Do?
What would MacGyver Do?

definitely science major
Three Rules for Student Research

1. Everyone must learn.
Three Rules for Student Research

1. Everyone must learn.
2. Everyone must have fun.
Three Rules for Student Research

1. Everyone must learn.
2. Everyone must have fun.
3. We try to contribute to science.

25 undergraduate co-authors

Paper of the year, 2008 & 2009
#1 Lesson Learned: logistics

- double purpose teaching and research
- get paid to do what you were going to do anyway
- biology education research is research
- small grant proposals take as much time to write as big ones
- volunteer to serve on NSF panel (increase success rate)
- collaborate widely (more fun, more success)
#2 Lesson Learned: human capital

- keep students multiple years vs. set them free
- recruiting minority students is different
- use your classes to troll for research students
- undergraduate research is slower than a technician research
#3 Lesson Learned: choose wisely

- design modular projects
- choose an inexpensive system
- avoid maintenance costs/time
- research groups ≥ 4 take less effort than ≤ 3
Start at the Beginning: 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

- Information
- Homeostasis
- Emergent Properties
- Cells
- Evolution
Five by Five Matrix of Biology

- Information
- Homeostasis
- Emergent Properties
- Evolution
- Cells

- Molecular
- Ecological System
- Population
- Organismal
- Cellular
Five by Five Matrix of Biology

- Information
- Molecular
- Ecological System
- Organismal
- Population
- Cellular
- Homeostasis
- Evolution
- Information
- Molecular
- Ecological System
- Organismal
- Population
- Cellular
- Emergent Properties
- Cells
- Molecular
- Information
- Population
- Organismal
- Cellular
- Information
- Molecular
- Ecological System
- Organismal
- Population
- Cellular
- Information
- Molecular
- Ecological System
- Organismal
- Population
- Cellular

Saturday, July 28, 2012
Five by Five Matrix of Biology
Five by Five Matrix of Biology
Five by Five Matrix of Biology
Five by Five Matrix of Biology
BioMath Explorations
BioMath Exploration 6.3

How can you fit exponential curves to data?
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

$p = 0.97$

new

traditional

Fall 2010

 +/- SEM

Saturday, July 28, 2012
Student Content Assessment

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

$p = 0.06$

$p = 0.97$

Fall 2010

Spring 2011

new

traditional

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

% Correct

Traditional | New

$p = 0.043$
Student Skills Assessment

Percent Correct

First  |  Second  |  Third  |  Fourth
Traditional (quiz averages)  
New (quiz averages)  

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

Saturday, July 28, 2012
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
Golden Gate Assembly Method

promoter + RBS + RFP

RBS

RFP

origin

antibiotic resistance

plasmid backbone
Eco RI

GAATTC
CTTAAG palindrome

type II
Eco RI

GAATTTC
CTTAAG

type II

palindrome
Eco RI

type II
Eco RI

G
CTTAA

AATTC
G

type II
Bsa I

GAGACC
CTCTG

not a palindrome

type IIIs
Bsa I

1234nGAGACC
----nCTCTGG

type IIIs
Bsa I

1234nGAGACC
nCTCTGG

type IIIs
Bsa I

GGTCTCn

CCAGAGn1234

type IIIs
Bsa I

GGTCTCn
CCAGAGn1234

type IIIs
Bsa I

1234 nGAGACC
----- nCTCTGG

GGTCTCn ----
CCAGAGn 1234

cuts left

cuts right
Bsa I

CGAC\textcolor{red}{tGAGACC}\textcolor{blue}{(TT)} GGTCTCaGCGG

GCTGaCTCTGG\textcolor{blue}{(TT)} CCAGAGtCGCC

Bsa I
CGAC\textsuperscript{t}GAGACC\textsuperscript{(TT)}GGTCTCa
\textsuperscript{a}CTCTGG\textsuperscript{(TT)}CCAGAG\textsuperscript{t}CGCC

GCGG

GCTG

RBS + RFP

CGAC\textsuperscript{(promoter)}

(promoter)CGCC
GCTG
GCGG
CGAC (promoter) CGCC

promoter + RBS + RFP

RBS RFP
GGA Ligation Method

TT + RBS + RFP

TT

RBS

RFP

BsaI + Ligase

TT + RBS + RFP

origin

antibiotic resistance

plasmid backbone
GGA Ligation Method

promoter + RBS + RFP

RBS

RFP

BsaI + Ligase

origin

antibiotic resistance

plasmid backbone
GGA Ligation Method

promoter + RBS + RFP

no gel purifications!

plasmid backbone

origin

antibiotic resistance
GGA Ligation Method

promoter + RBS + RFP

no gel purifications!

origin → antibiotic resistance
plasmid backbone

Saturday, July 28, 2012
### Registry of Functional Promoters

#### Campbell M Lab Parts

**Favorite Campbell M Lab Parts**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
<th>Designer</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blu_110001</td>
<td>Coding</td>
<td>Crease with Bgl restriction sites and 1-Classes 2-SAT Problem Inserted</td>
<td>Eric Sawyer</td>
<td>1566</td>
</tr>
<tr>
<td>Blu_110002</td>
<td>Composite</td>
<td>5'Thrine+5'RBS+2xSAT+Cloning+5'gRNA-COGACG</td>
<td>Eric Sawyer</td>
<td>1307</td>
</tr>
<tr>
<td>Blu_110003</td>
<td>Generator</td>
<td>5'Thrine+5'RBS+2xSAT+Cloning</td>
<td>Eric Sawyer</td>
<td>1149</td>
</tr>
<tr>
<td>Blu_110004</td>
<td>Reporter</td>
<td>5'Thrine+5'RBS+5'RFP+GFP</td>
<td>Eric Sawyer</td>
<td>807</td>
</tr>
<tr>
<td>Blu_110005</td>
<td>Other</td>
<td>Palindrome Stop Sequence</td>
<td>Eric Sawyer</td>
<td>221</td>
</tr>
<tr>
<td>Blu_110006</td>
<td>Intermediate</td>
<td>Leu-5'RBS-Stop-Sequence-LodP</td>
<td>Eric Sawyer</td>
<td>906</td>
</tr>
<tr>
<td>Blu_110007</td>
<td>Intermediate</td>
<td>pLeu-RBS-LeuP-5'RBS-Sequence-LodP</td>
<td>Eric Sawyer</td>
<td>906</td>
</tr>
<tr>
<td>Blu_110008</td>
<td>Composite</td>
<td>pLpsp-RNA COGACG</td>
<td>Eric Sawyer</td>
<td>426</td>
</tr>
<tr>
<td>Blu_110009</td>
<td>Composite</td>
<td>5'gRNA CGGACG</td>
<td>Eric Sawyer</td>
<td>426</td>
</tr>
<tr>
<td>Blu_110010</td>
<td>Composite</td>
<td>5'gRNA CGGACG</td>
<td>Eric Sawyer</td>
<td>426</td>
</tr>
<tr>
<td>Blu_110011</td>
<td>Composite</td>
<td>5'gRNA CGGACG</td>
<td>Eric Sawyer</td>
<td>426</td>
</tr>
<tr>
<td>Blu_110012</td>
<td>Intermediate</td>
<td>RBS-RFP-RBS</td>
<td>Eric Sawyer</td>
<td>747</td>
</tr>
<tr>
<td>Blu_110013</td>
<td>Coding</td>
<td>Rist with 1 Genes 2-SAT Problem</td>
<td>Eric Sawyer</td>
<td>635</td>
</tr>
<tr>
<td>Blu_110014</td>
<td>Coding</td>
<td>Rist with 2 Genes 2-SAT Problem</td>
<td>Eric Sawyer</td>
<td>852</td>
</tr>
<tr>
<td>Blu_110015</td>
<td>Composite</td>
<td>1 Classes 2-SAT Problem with Framed Lox Lox and a GFP Repressor</td>
<td>Eric Sawyer</td>
<td>2754</td>
</tr>
<tr>
<td>Blu_110016</td>
<td>Composite</td>
<td>2 Classes 2-SAT Problem with Framed Lox Lox and a GFP Repressor</td>
<td>Eric Sawyer</td>
<td>2777</td>
</tr>
<tr>
<td>Blu_110017</td>
<td>Composite</td>
<td>TTC-lop-RBS-lop-2SAT 2 classes-RBS-GFP-lop-RBS-LoxR-LuxR-RNA</td>
<td>Eric Sawyer</td>
<td>3565</td>
</tr>
<tr>
<td>Blu_110018</td>
<td>Protein-Domain</td>
<td>First Half of AtpG-gene</td>
<td>Catherine Doyle</td>
<td>466</td>
</tr>
<tr>
<td>Blu_110019</td>
<td>Protein-Domain</td>
<td>First half of AtpG-gene</td>
<td>Julia Ferguson</td>
<td>457</td>
</tr>
<tr>
<td>Blu_110020</td>
<td>Protein-Domain</td>
<td>Second Half of AtpG</td>
<td>Catherine Doyle</td>
<td>809</td>
</tr>
<tr>
<td>Blu_110021</td>
<td>Protein-Domain</td>
<td>First Half of Pyc</td>
<td>Catherine Doyle</td>
<td>499</td>
</tr>
<tr>
<td>Blu_110022</td>
<td>Protein-Domain</td>
<td>Second Half of Pyc</td>
<td>Catherine Doyle</td>
<td>229</td>
</tr>
<tr>
<td>Blu_110023</td>
<td>Protein-Domain</td>
<td>First half of GAT gene</td>
<td>James Harden</td>
<td>434</td>
</tr>
<tr>
<td>Blu_110024</td>
<td>Protein-Domain</td>
<td>Second half of GAT gene</td>
<td>James Harden</td>
<td>570</td>
</tr>
<tr>
<td>Blu_110025</td>
<td>Other</td>
<td>Other plasmid insert for Rist Golden Gate Assembly of promoter</td>
<td>Malcolm Campbell</td>
<td>879</td>
</tr>
<tr>
<td>Blu_110026</td>
<td>Regulatory</td>
<td>The promoter of pOpPha</td>
<td>Maggpie Berry</td>
<td>76</td>
</tr>
<tr>
<td>Blu_110027</td>
<td>Regulatory</td>
<td>pOpPha is an inducible promoter induced by phasatide activation</td>
<td>Scott Hall</td>
<td>76</td>
</tr>
<tr>
<td>Blu_110028</td>
<td>Regulatory</td>
<td>Cotelormid promoter 2 or Gene 1 of T7 transactase RNA Pol</td>
<td>Carolina Varela</td>
<td>110</td>
</tr>
<tr>
<td>Blu_110029</td>
<td>Regulatory</td>
<td>pOpPha promoter</td>
<td>Mel Maniati</td>
<td>90</td>
</tr>
<tr>
<td>Blu_110030</td>
<td>Regulatory</td>
<td>dexam promoter</td>
<td>Chris Plate</td>
<td>121</td>
</tr>
<tr>
<td>Blu_110031</td>
<td>Regulatory</td>
<td>dexam promoter</td>
<td>Morgan Stadler</td>
<td>44</td>
</tr>
<tr>
<td>Blu_110032</td>
<td>Regulatory</td>
<td>Promoter Induced by DNA damage</td>
<td>Eric Ball</td>
<td>52</td>
</tr>
<tr>
<td>Blu_110033</td>
<td>Regulatory</td>
<td>GalP Promoter-induced by Galactose</td>
<td>Andrés Toby</td>
<td>75</td>
</tr>
<tr>
<td>Blu_110034</td>
<td>Coding</td>
<td>Rist with 3 classes 2-SAT problem</td>
<td>Eric Sawyer</td>
<td>886</td>
</tr>
<tr>
<td>Blu_110035</td>
<td>Composite</td>
<td>Rist with 3 classes 2-SAT problem</td>
<td>Eric Sawyer</td>
<td>2653</td>
</tr>
<tr>
<td>Blu_110036</td>
<td>Coding</td>
<td>Rist with 4 classes 2-SAT problem</td>
<td>Eric Sawyer</td>
<td>2886</td>
</tr>
<tr>
<td>Blu_110037</td>
<td>Coding</td>
<td>Rist with 4 classes 2-SAT problem</td>
<td>Eric Sawyer</td>
<td>2704</td>
</tr>
<tr>
<td>Blu_110038</td>
<td>Composite</td>
<td>Rist with 4 classes 2-SAT problem</td>
<td>Eric Sawyer</td>
<td>2883</td>
</tr>
<tr>
<td>Blu_110039</td>
<td>RNAS</td>
<td>pOpPha-RNA COGACG</td>
<td>Eric Sawyer</td>
<td>201</td>
</tr>
<tr>
<td>Blu_110040</td>
<td>Protein-Domain</td>
<td>Tyree</td>
<td>Julia Ferguson</td>
<td>930</td>
</tr>
<tr>
<td>Blu_110041</td>
<td>Protein-Domain</td>
<td>Tyree</td>
<td>Julia Ferguson</td>
<td>930</td>
</tr>
<tr>
<td>Blu_110042</td>
<td>Composite</td>
<td>Luxa producer and XDP gate</td>
<td>Malcolm Campbell</td>
<td>2779</td>
</tr>
<tr>
<td>Blu_110043</td>
<td>Composite</td>
<td>Luxa producer and RFP (Rho) + RBS (rev) + 5PLux (for)</td>
<td>Malcolm Campbell</td>
<td>1956</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Format: Subparts</th>
<th>Search:</th>
<th>Length: 101 bp</th>
<th>Context: Part only</th>
<th>Get selected sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 11 21 31 41 51</td>
<td>61 71 81 91</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Assembly Compatibility: 10 12 21 23 25
Student Sample

Part: BBa_J100033: Experience

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

![Graph showing mean fluorescence per cell density for different conditions.]

- **A**: Experimental:
- **B**: Control
- **C**: Negative control
- **D**: Positive control
- **E**: Negative control with IPTG
- **F**: Positive control with IPTG

* p < 0.01
GCAT Faculty Workshop
Synthetic Biology

15 pairs of faculty
1 Bio + 1 Other
NSF & HHMI
Synthetic Biology Research at Davidson College
Synthetic Biology: Win-Win

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

Win #1: your design functions as expected.

Win #2: your design fails but you uncover basic biology
Real World Applications of Synthetic Biology
Land Mine Detection
Land Mine Detection
New weed may flag land mines

By John K. Borchardt | Contributor to The Christian Science Monitor
Synthetic Biology
Land Mine Detection

WARNING SIGN: The bioengineered Thales cress turns red when exposed to a mine byproduct.
COURTESY OF ARESA BIODETECTION

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
Building Bacterial Computers
Can we build a bacterial cryptographic hash function?
What is a hash function?

The diagram illustrates the process of a hash function. It starts with a document on the left, which is hashed to produce a hash code, represented by "HGTf34$2". This hash code is then used to encrypt a text message that says "iGEM IS COOL!" on the right side of the diagram.
Can Bacteria Perform a Hash Function?

HGTf34$2
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>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

![XOR Gate Diagram]
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>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Diagram:**

```
  A
 / \  
/     \  
B       Y
```
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>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

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

CAB = 010000001

HASH VALUE = 0
Time-Delayed Bacterial Growth
Time-Delayed Bacterial Growth
DNA-based XOR Logic Gate
DNA-based XOR Logic Gate

High Osmolarity (Input A)

3OC6 (Input B)

RFP  RBS  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>
</tr>
</tbody>
</table>
DNA-based XOR Logic Gate

<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>
</tr>
</tbody>
</table>
DNA-based XOR Logic Gate

<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>
</tr>
</tbody>
</table>
DNA-based XOR Logic Gate

<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>
</tr>
</tbody>
</table>
DNA-based XOR Logic Gate

<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>
</tr>
</tbody>
</table>
Testing Bacterial XOR Logic Gate

Relative Fluorescence

<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>

High Osmolarity (Input A) 3OC6 (Input B)

Testing Bacterial XOR Logic Gate

Saturday, July 28, 2012
Testing Bacterial XOR Logic Gate

<table>
<thead>
<tr>
<th>Relative Fluorescence</th>
<th>XOR +LuxR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RFP</td>
</tr>
<tr>
<td></td>
<td>GFP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>LB</th>
<th>-</th>
<th>-</th>
<th>+</th>
<th>+</th>
</tr>
</thead>
<tbody>
<tr>
<td>3OC6</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
Testing Bacterial XOR Logic Gate

Relative Fluorescence

<table>
<thead>
<tr>
<th></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>
<td>+</td>
</tr>
</tbody>
</table>

High Osmolarity (Input A)

RFP

GFP

XOR +LuxR

RFP

GFP

Testing Bacterial XOR Logic Gate

Saturday, July 28, 2012
Testing Bacterial XOR Logic Gate

<table>
<thead>
<tr>
<th></th>
<th>LB</th>
<th>3OC6</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFP Fluorescence</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>GFP Fluorescence</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>RFP Condition</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>GFP Condition</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>
Testing Bacterial XOR Logic Gate

<table>
<thead>
<tr>
<th></th>
<th>LB</th>
<th>3OC6</th>
</tr>
</thead>
<tbody>
<tr>
<td>XOR +LuxR</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>RFP</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>GFP</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>
Testing Bacterial XOR Logic Gate

Relative Fluorescence

<table>
<thead>
<tr>
<th></th>
<th>LB</th>
<th>3OC6</th>
</tr>
</thead>
<tbody>
<tr>
<td>XOR +LuxR</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>RFP</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>GFP</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
pLux + LuxR Promotes Backwards

Relative Fluorescence

<table>
<thead>
<tr>
<th></th>
<th>LuxR</th>
<th>3OC6</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.2</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>0.4</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>0.6</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>0.8</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>1</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>1.2</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

pLux

RBS

RFP
pLux + LuxR Promotes Backwards

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

Relative Fluorescence

Saturday, July 28, 2012
pLux + LuxR Promotes Backwards

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

Relative Fluorescence
pLux + LuxR Promotes Backwards

Relative Fluorescence

<table>
<thead>
<tr>
<th>LuxR</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>3OC6</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Saturday, July 28, 2012
pLux + LuxR Promotes Backwards

Relative Fluorescence

<table>
<thead>
<tr>
<th></th>
<th>LuxR</th>
<th>3OC6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>-</strong> LuxR</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>+</strong> LuxR</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>-</strong> LuxR</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>+</strong> LuxR</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

RFP RBS pLux
pLux + LuxR Promotes Backwards

<table>
<thead>
<tr>
<th>LuxR</th>
<th>3OC6</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
Why build bacterial computers?
Evolution of Computers

iPhone in 2012

Saturday, July 28, 2012
Evolution of Bacterial Computers

*E. coli* in 2012

Living Hardware in 2022
The scenery only changes for the lead dog.
The scenery only changes for the lead dog.
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
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.”
“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?’ ”

anonymous student course evaluation, Dec. 2010
“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).”

Anonymous student course evaluation, Dec. 2010