Integrating Teaching and Research: What would MacGyver Do?

A. Malcolm Campbell
Biology Department and **GCAT**

DAVIDSON

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?

Saturday, July 28, 2012

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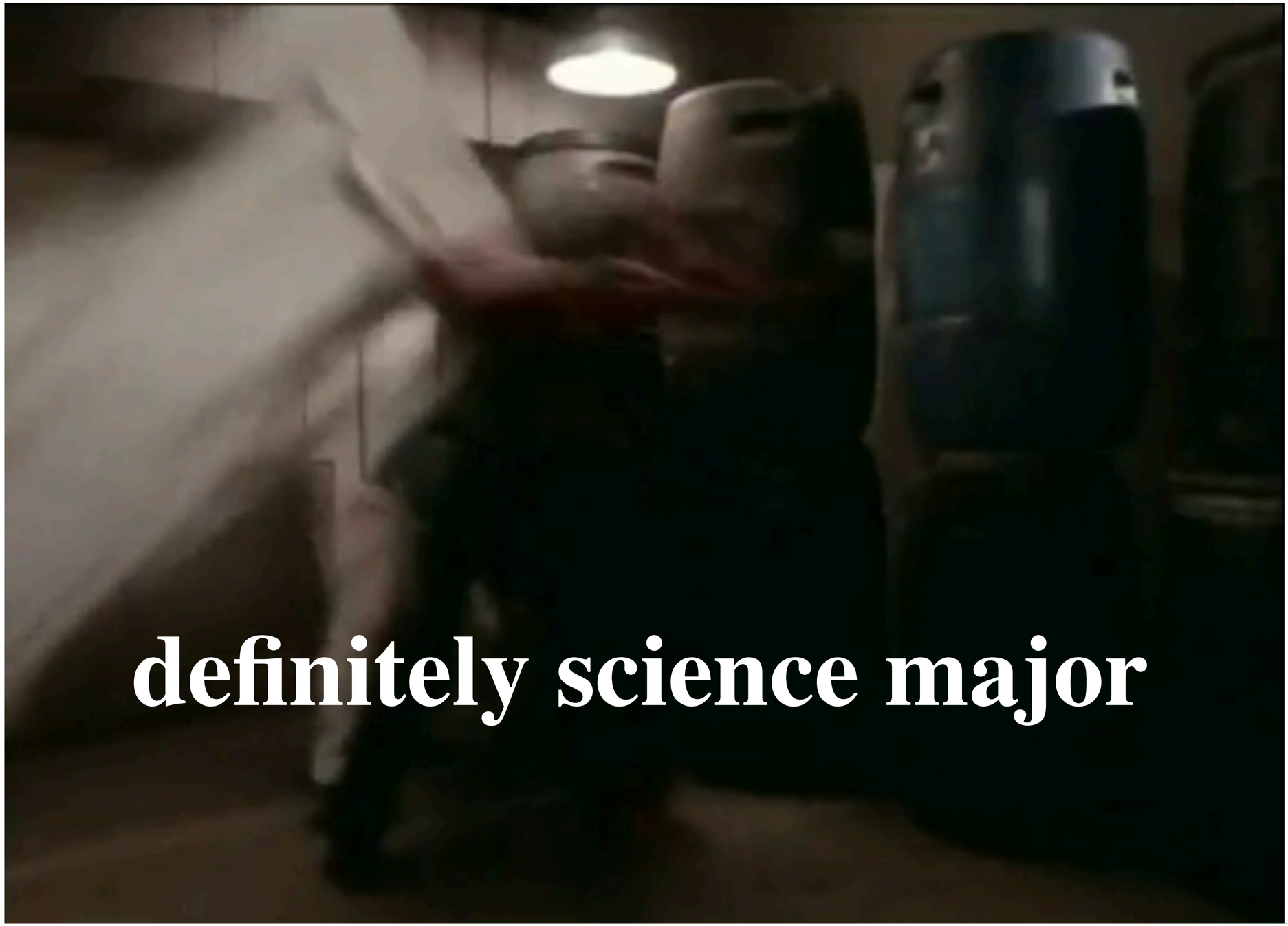


Three Rules for Student Research

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.

1. Research Open Access Highly accessed
45482 Accesses
Solving a Hamiltonian Path Problem with a bacterial computer
Jordan Baumgardner, Karen Acker, Oyinade Adefuye, Samuel Crowley, Will D
Heard, Andrew T Martens, Nickolaus Morton, Michelle Ritter, Amber Shoecraft
Amanda Valencia, Mike Waters, A Malcolm Campbell, Laurie J Heyer, Jeffrey L
Journal of Biological Engineering 2009, **3**:11 (24 July 2009)
Abstract | Full text | PDF | PubMed | F1000 Biology | ▸Editor's summary

2. Research Open Access Highly accessed
37052 Accesses
Engineering bacteria to solve the Burnt Pancake Problem
Karmella A Haynes, Marian L Broderick, Adam D Brown, Trevor L Butner, James O Dickson, W Lance Harden, Lane H Heard, Eric L Jessen, Kelly J Malloy, Brad J Ogden, Sabriya Rosemond, Samantha Simpson, Erin Zwack, A Malcolm Campbell, Todd T Eckdahl, Laurie J Heyer, Jeffrey L Poet
Journal of Biological Engineering 2008, **2**:8 (20 May 2008)
Abstract | Full text | PDF | PubMed | 1 comment | ▸Editor's summary

3. Methodology Open Access Highly accessed
23176 Accesses
Engineering BioBrick vectors from BioBrick parts
Reshma P Shetty, Drew Endy, Thomas F Knight
Journal of Biological Engineering 2008, **2**:5 (14 April 2008)
Abstract | Full text | PDF | PubMed | Cited on BioMed Central

JOURNAL OF BIOLOGICAL ENGINEERING

25 undergraduate co-authors

Paper of the year, 2008 &2009

#1 Lesson Learned: logistics

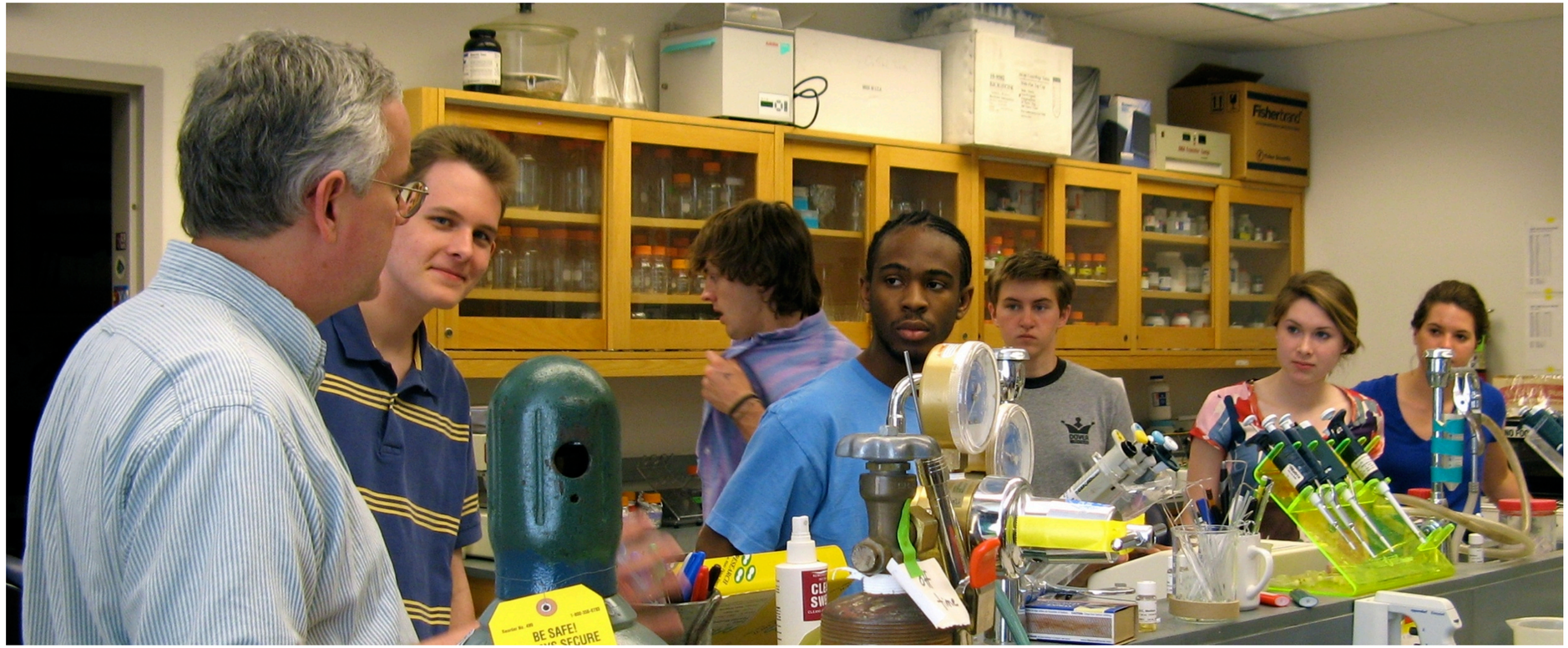
- double purpose teaching and research
- get paid to do what you were going to do anyway
- biology education research is research
- small grant proposals take as much time to write as big ones
- volunteer to serve on NSF panel (increase success rate)
- collaborate widely (more fun, more success)

#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….

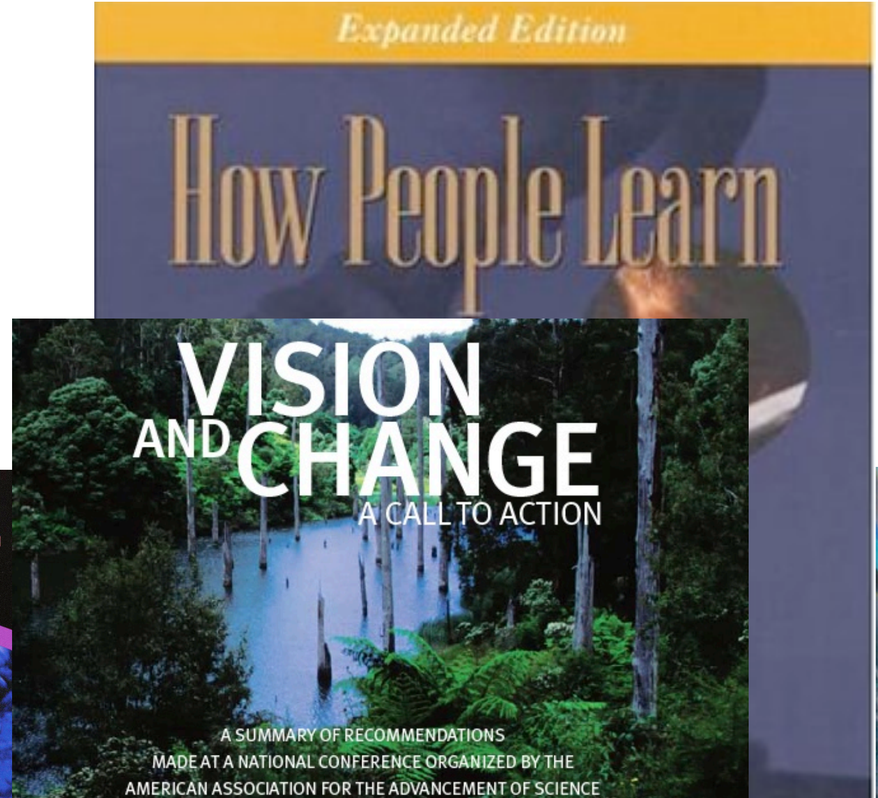
…how can we add more content?

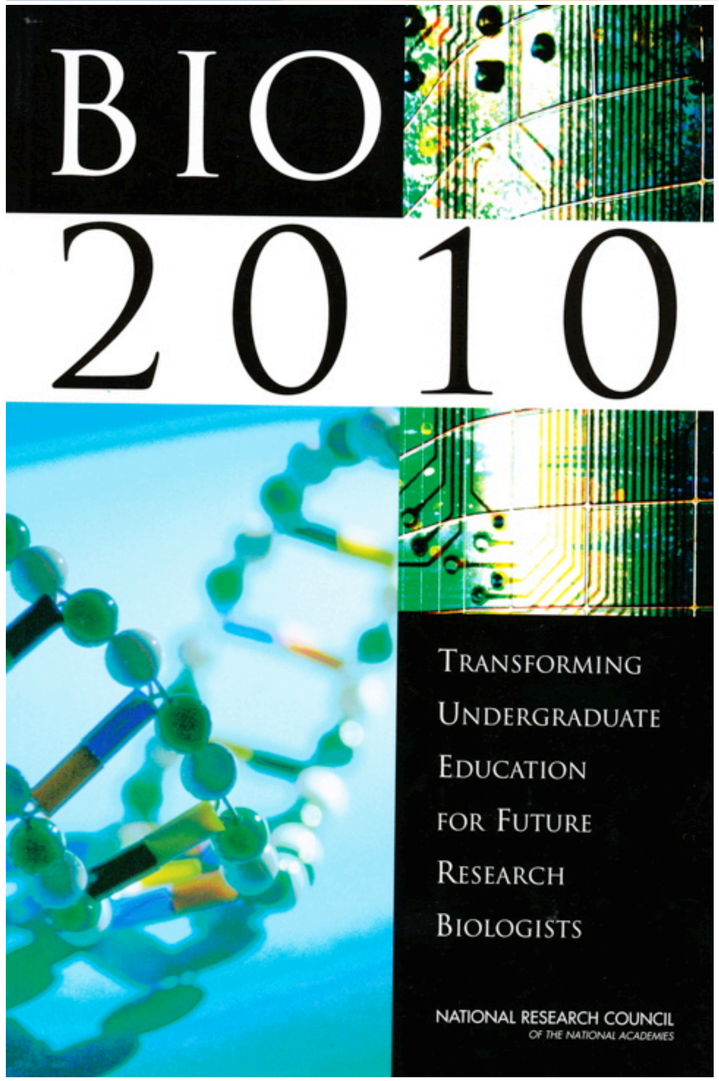
Too much content for the containers

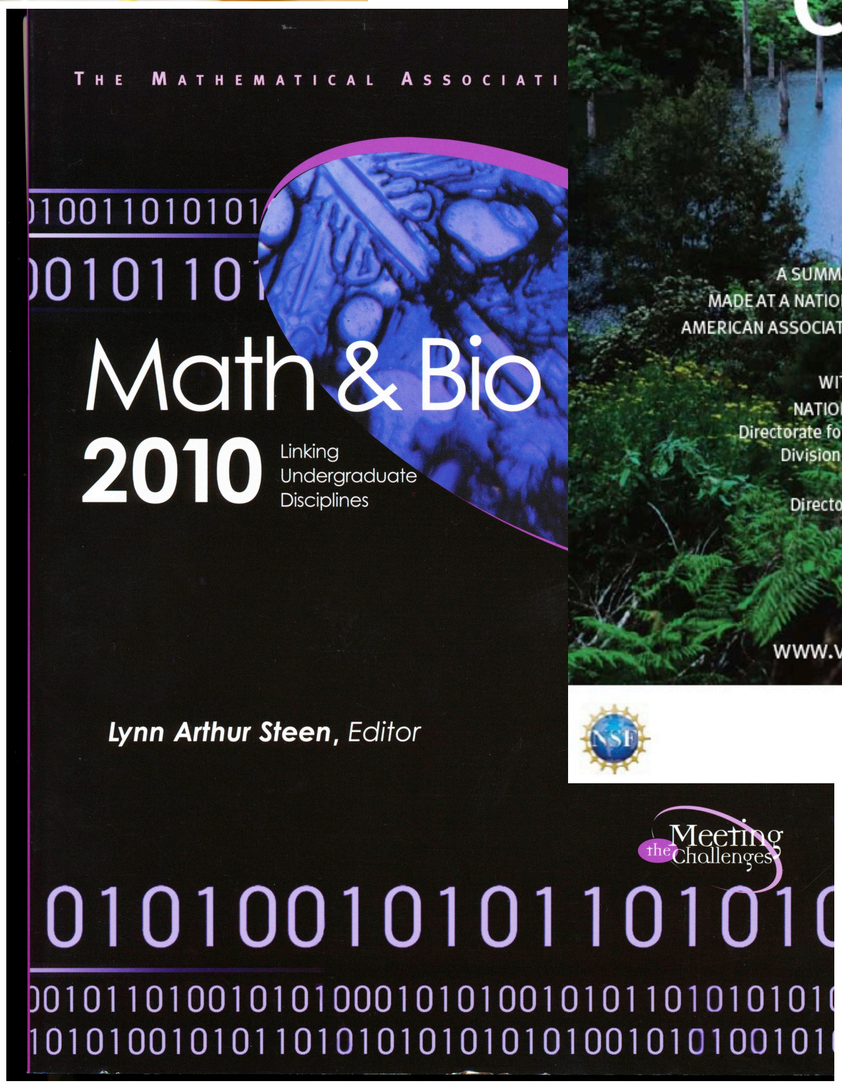
Saturday, July 28, 2012

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

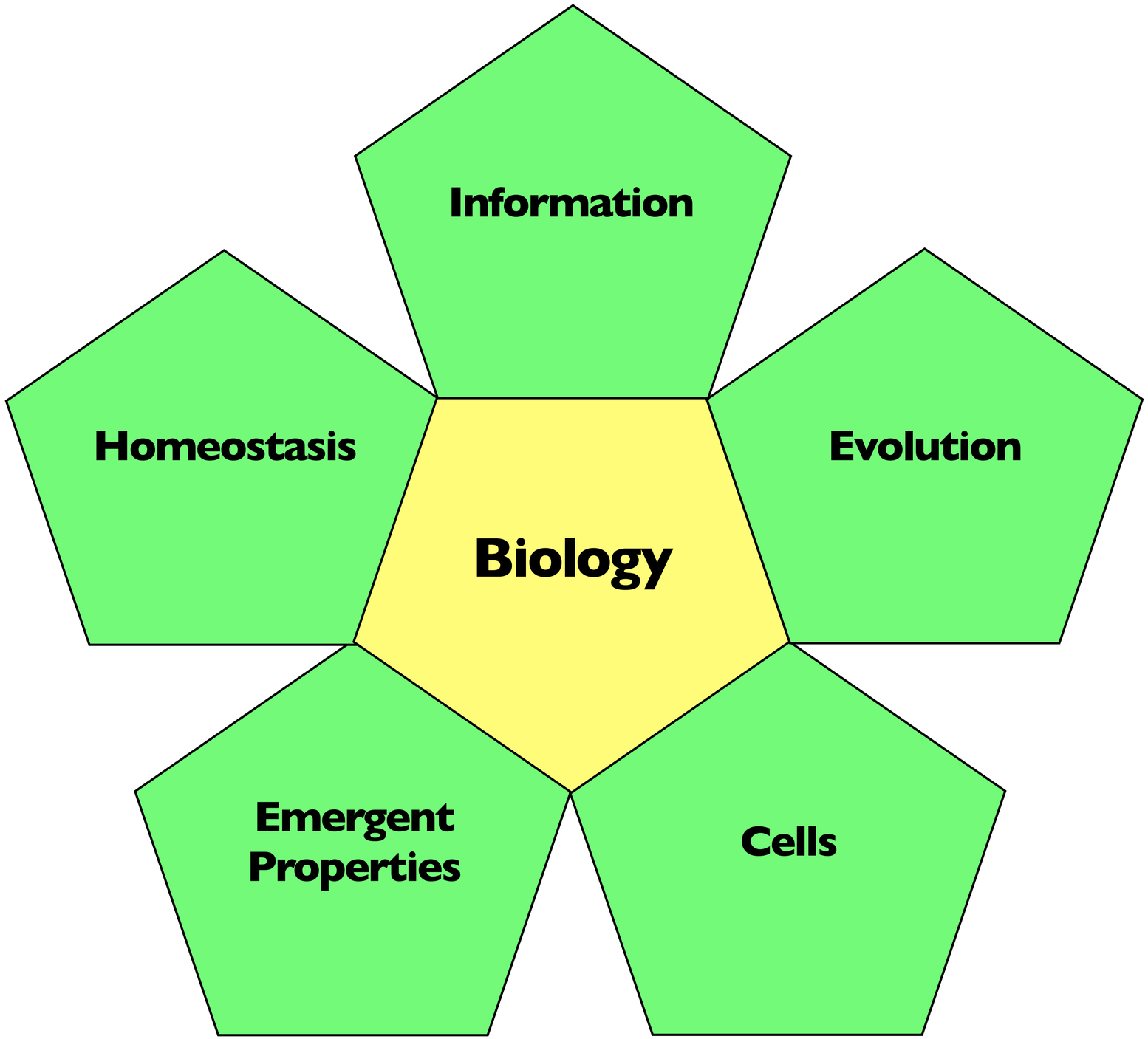
Cellular

Organismal

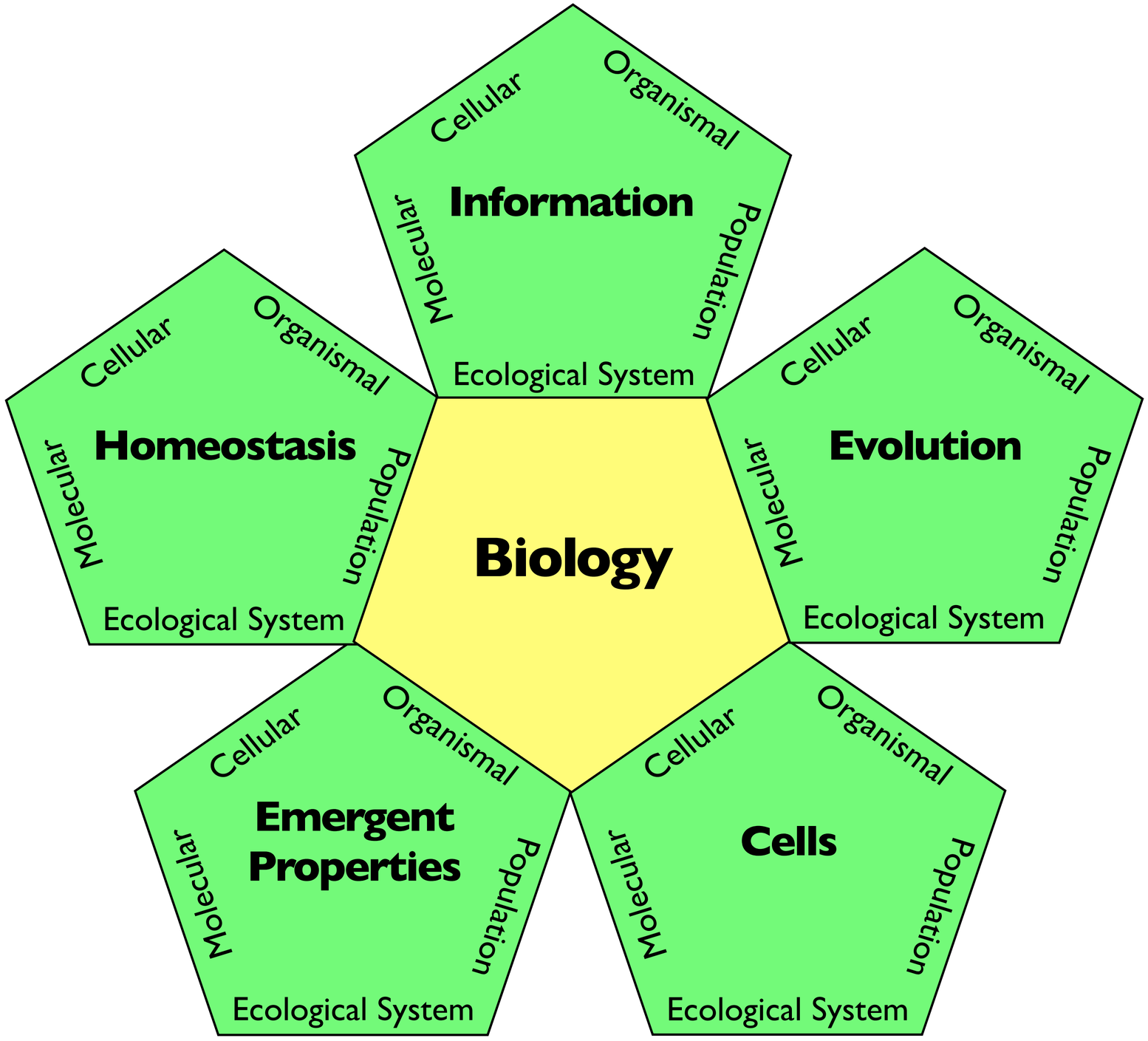
Population

Ecological System

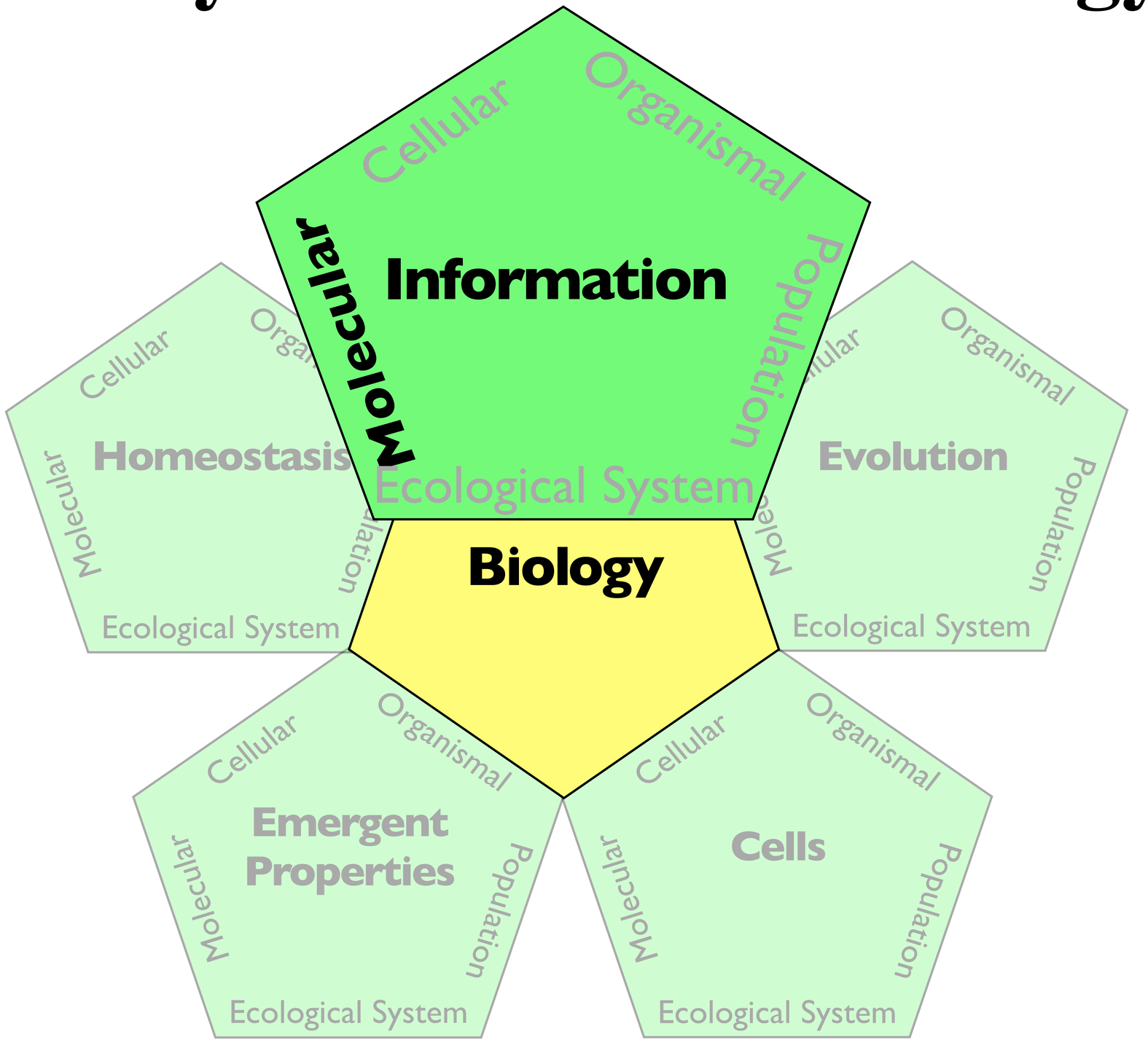
Five Big Ideas of Biology



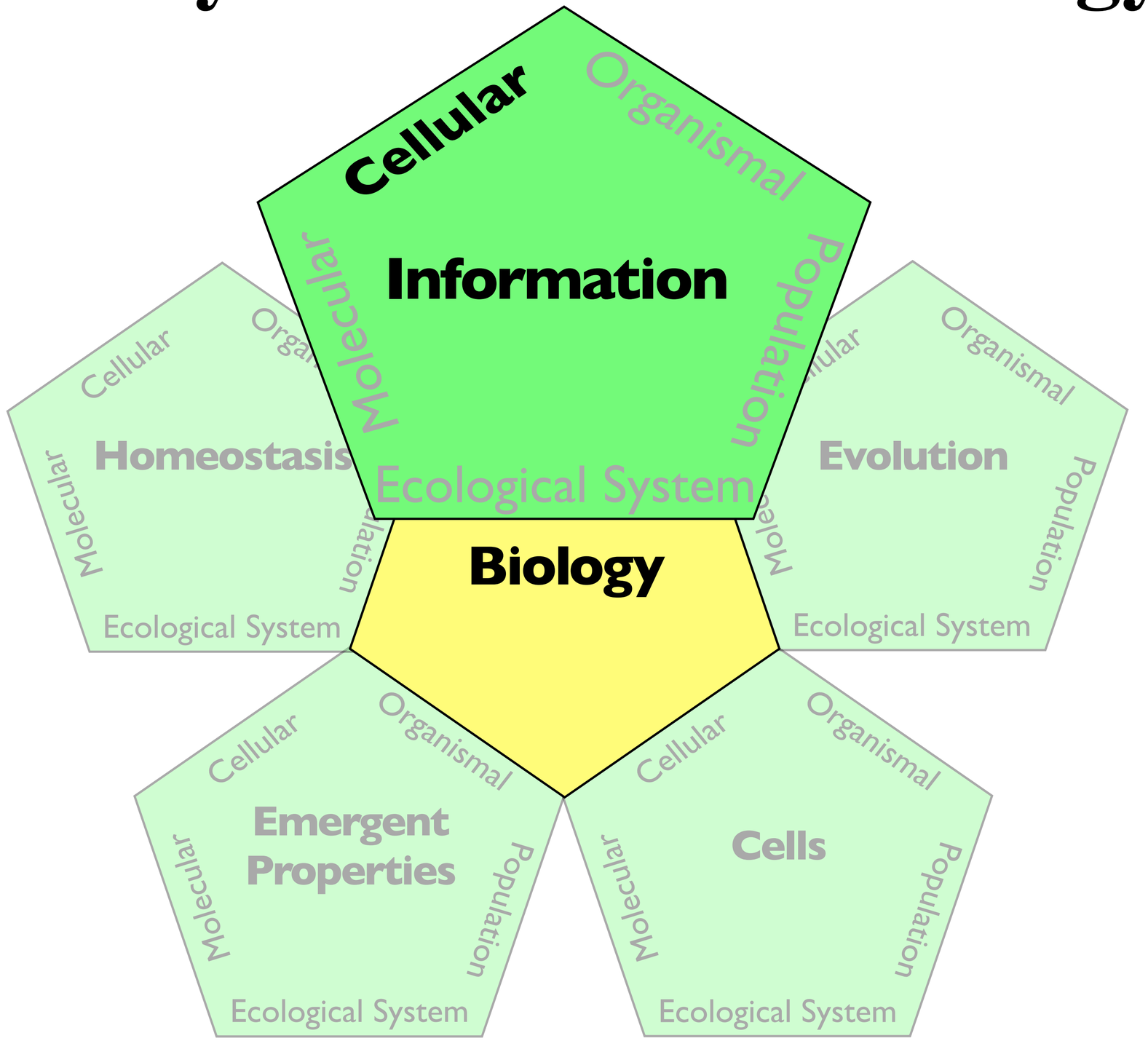
Five by Five Matrix of Biology



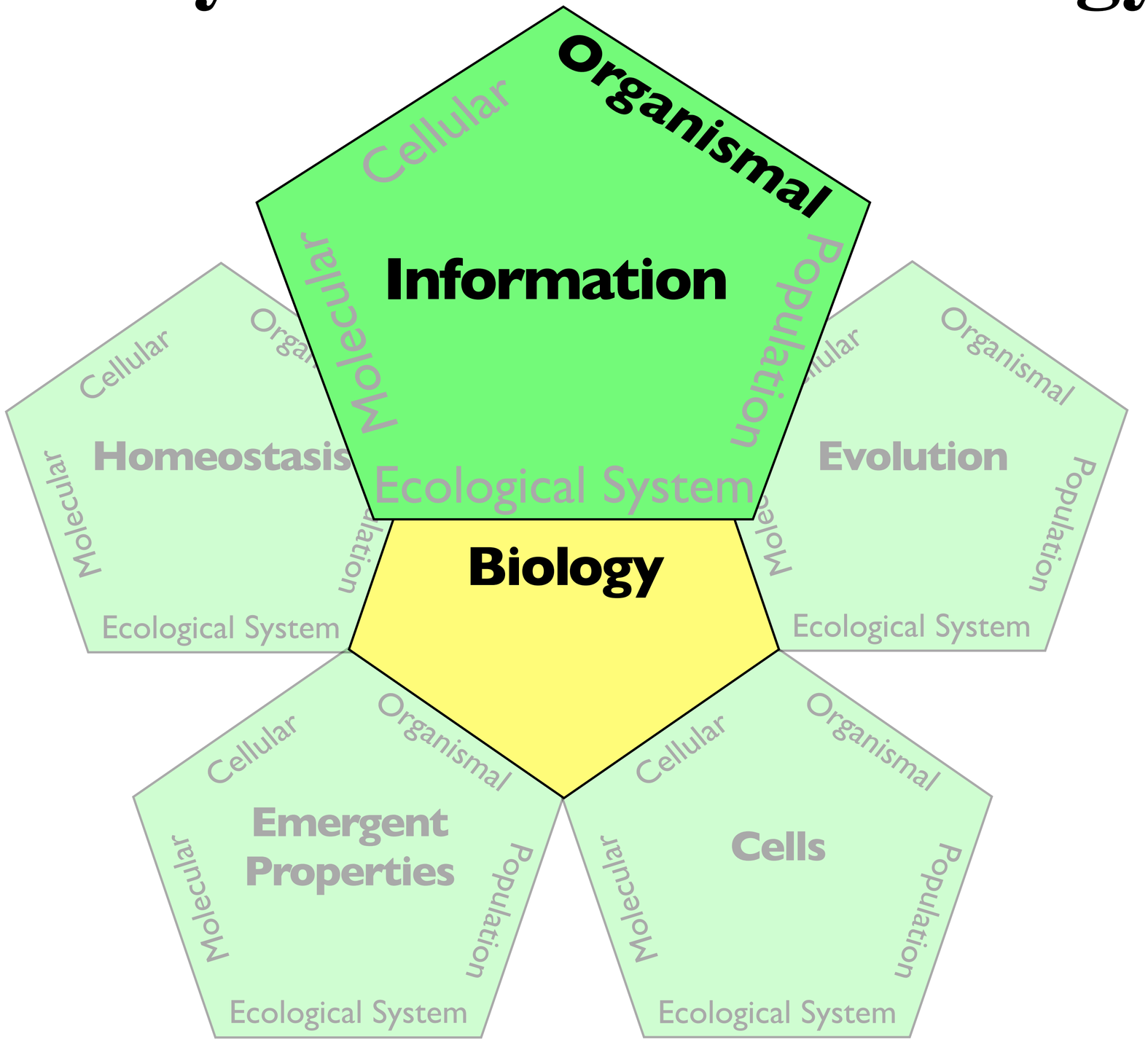
Five by Five Matrix of Biology



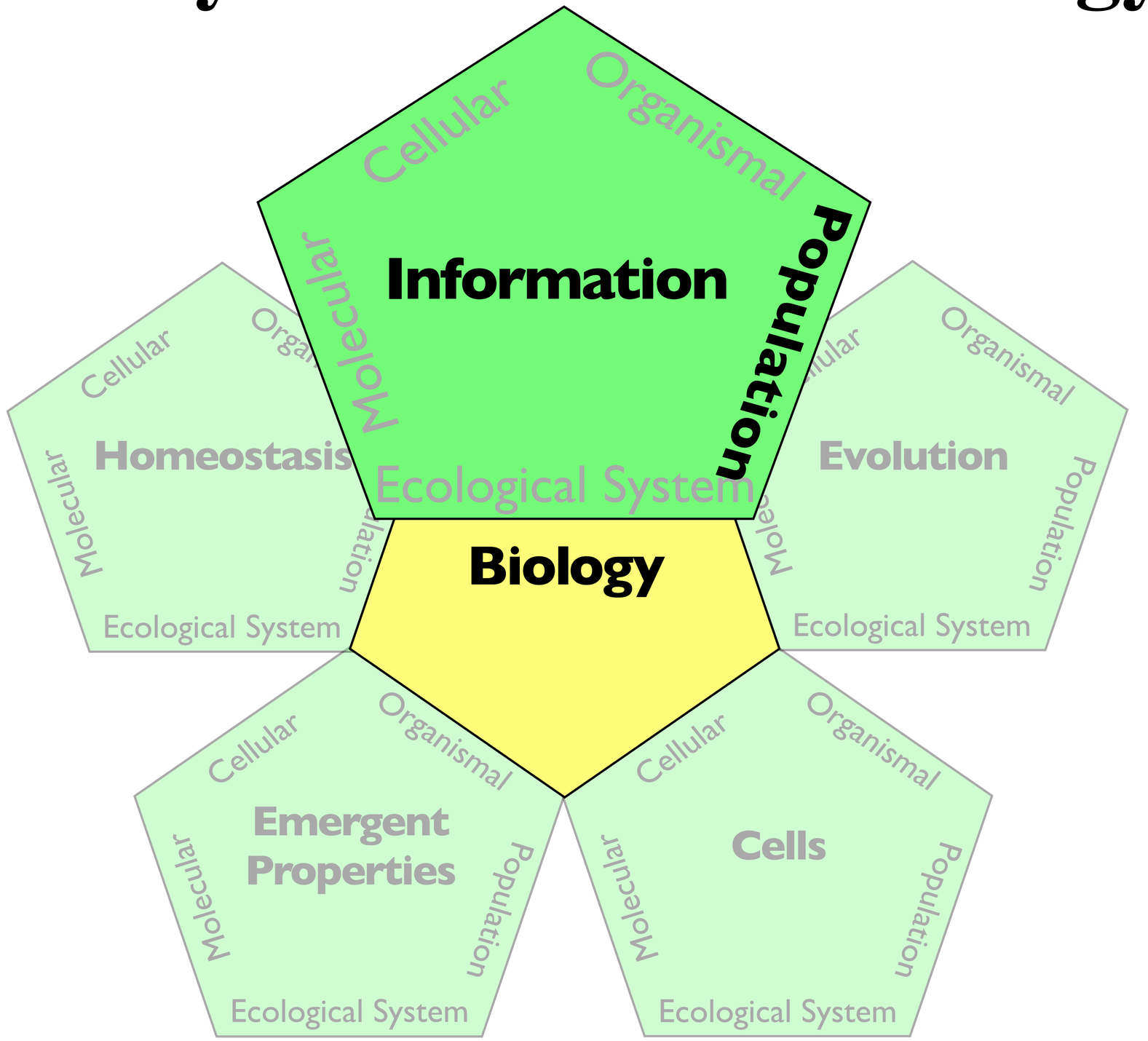
Five by Five Matrix of Biology



Five by Five Matrix of Biology



Five by Five Matrix of Biology



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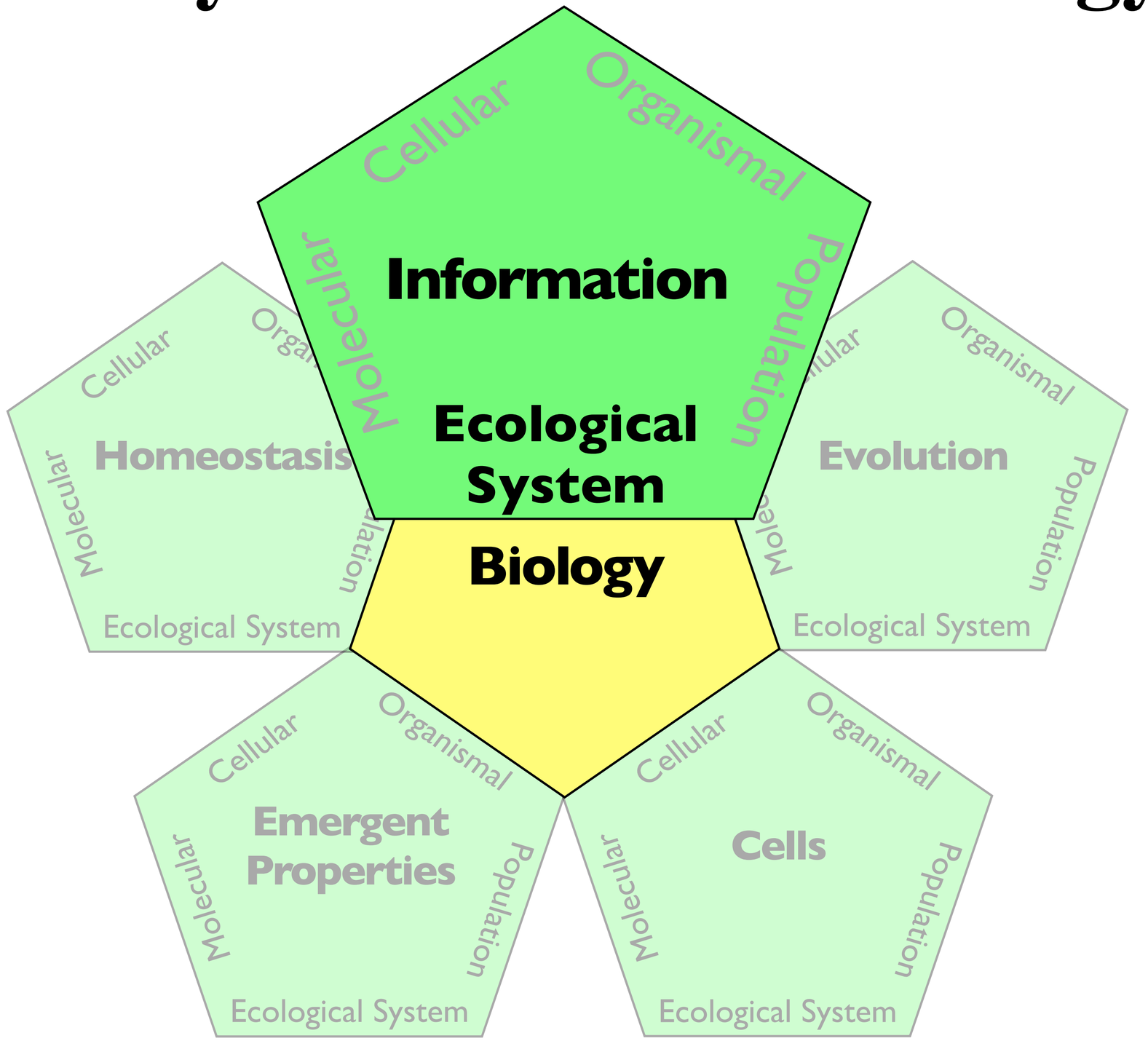

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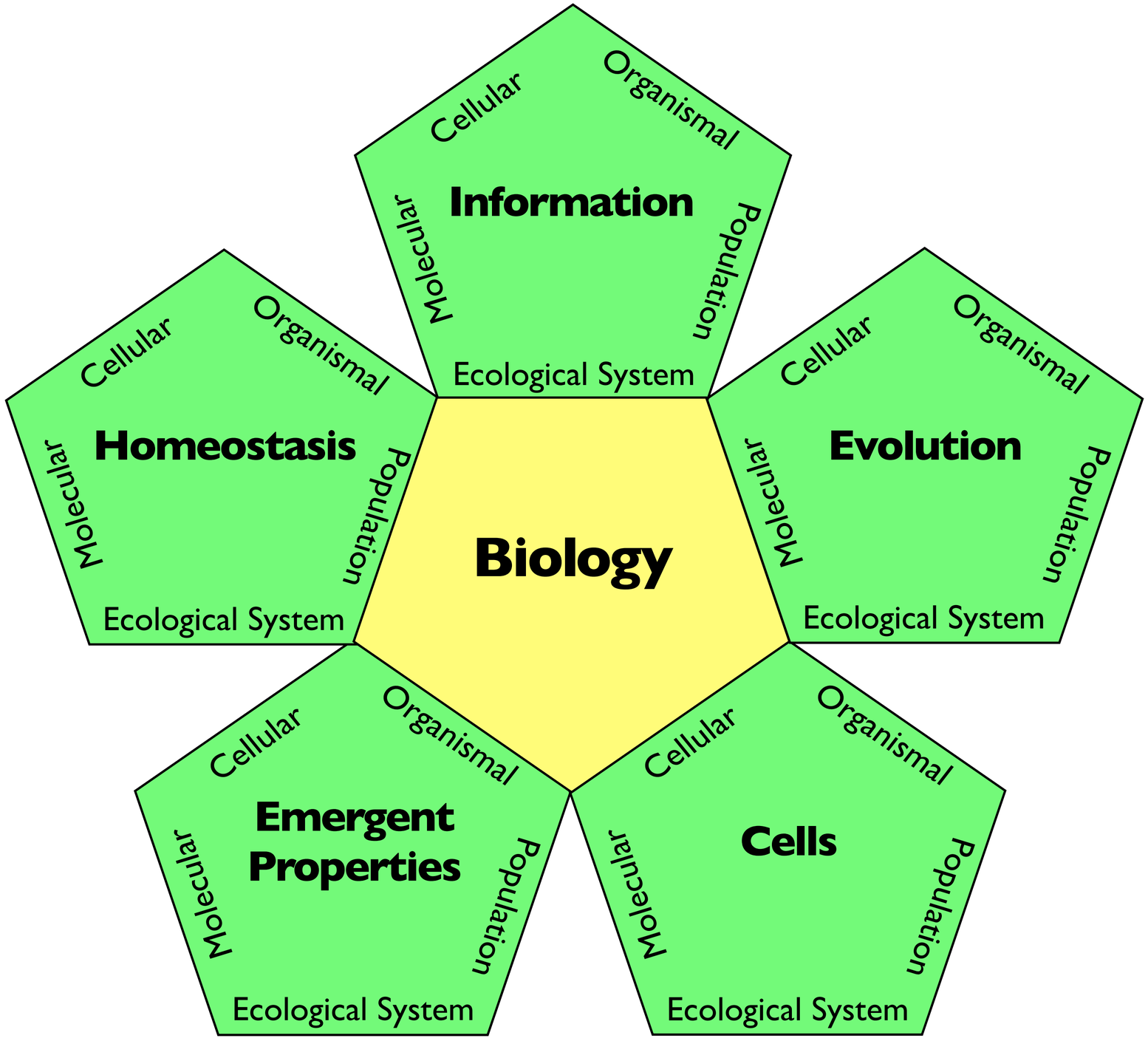
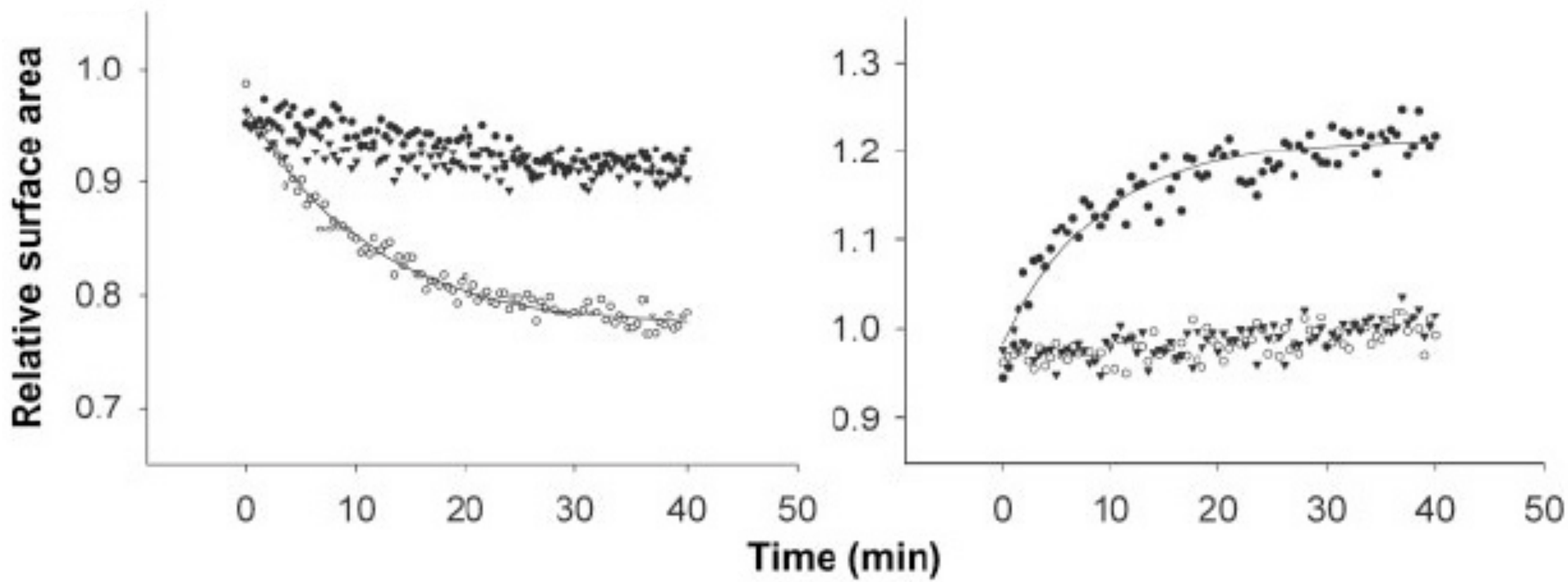


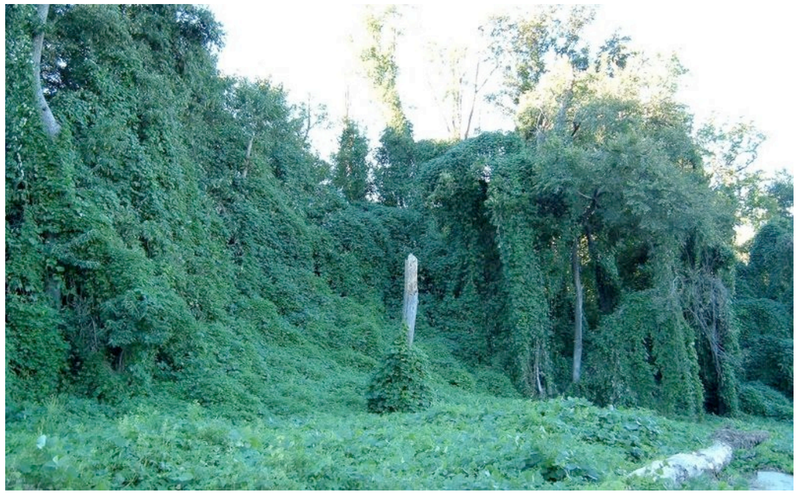
BioMath Explorations

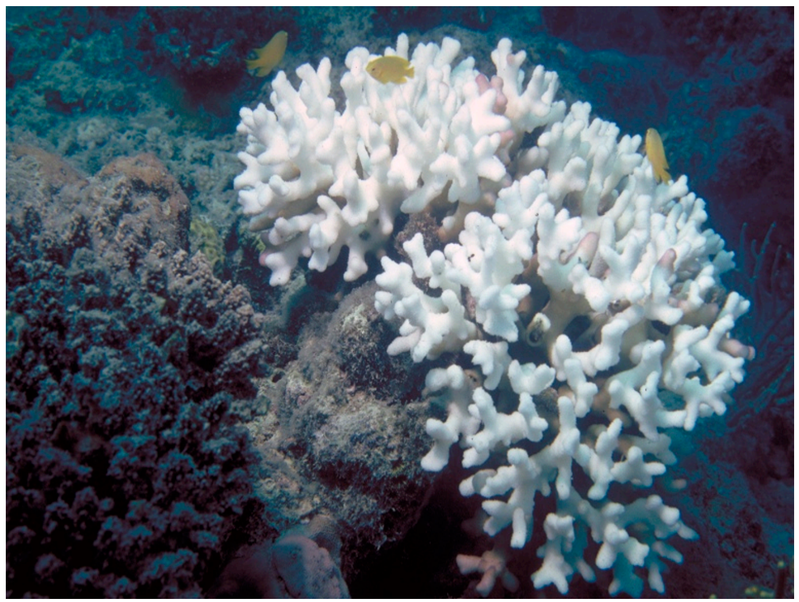
BioMath Exploration 6.3

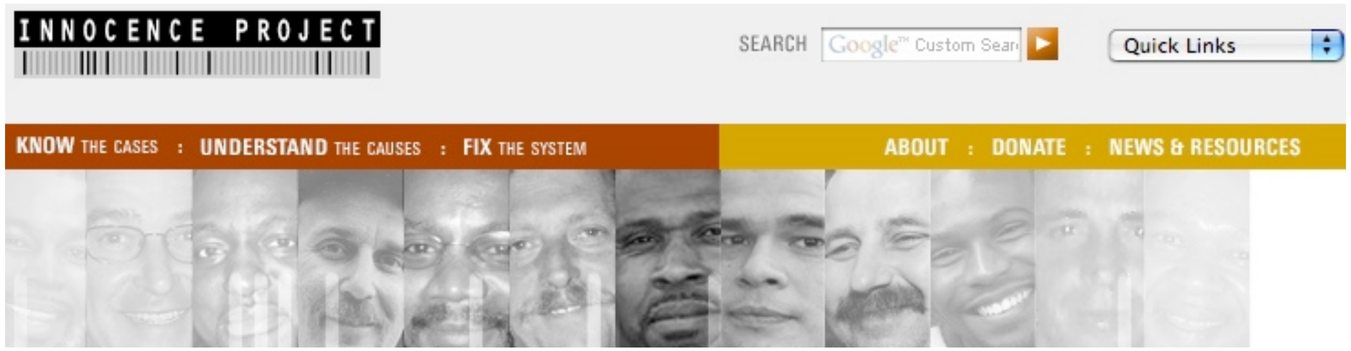
How can you fit exponential curves to data?



Ethical, Legal and Social Implications







Are religion and evolution compatible?

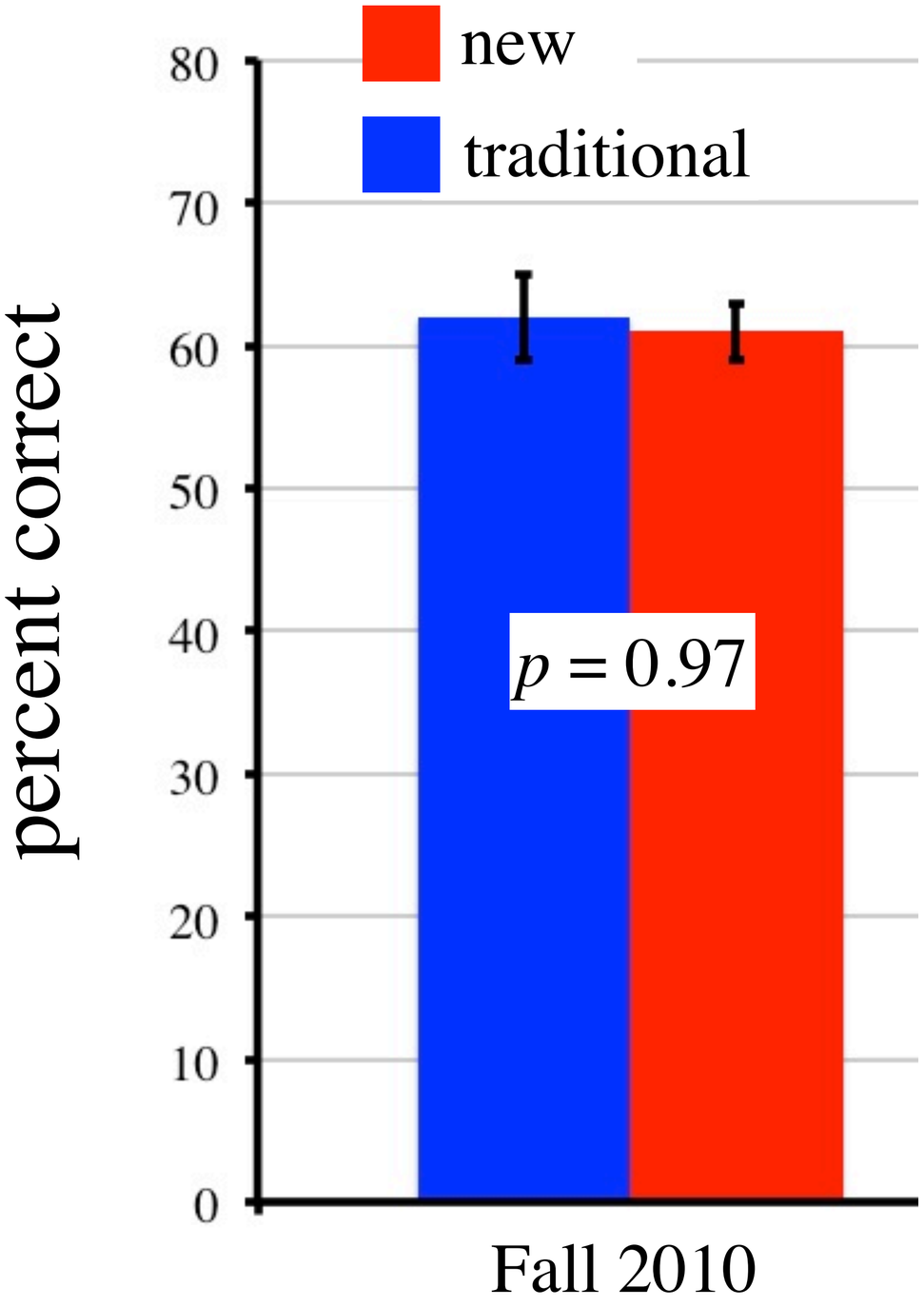
Is science possible if you are uncertain about what is true?

Does basic biology have any impact on the real world?

Who owns your DNA?

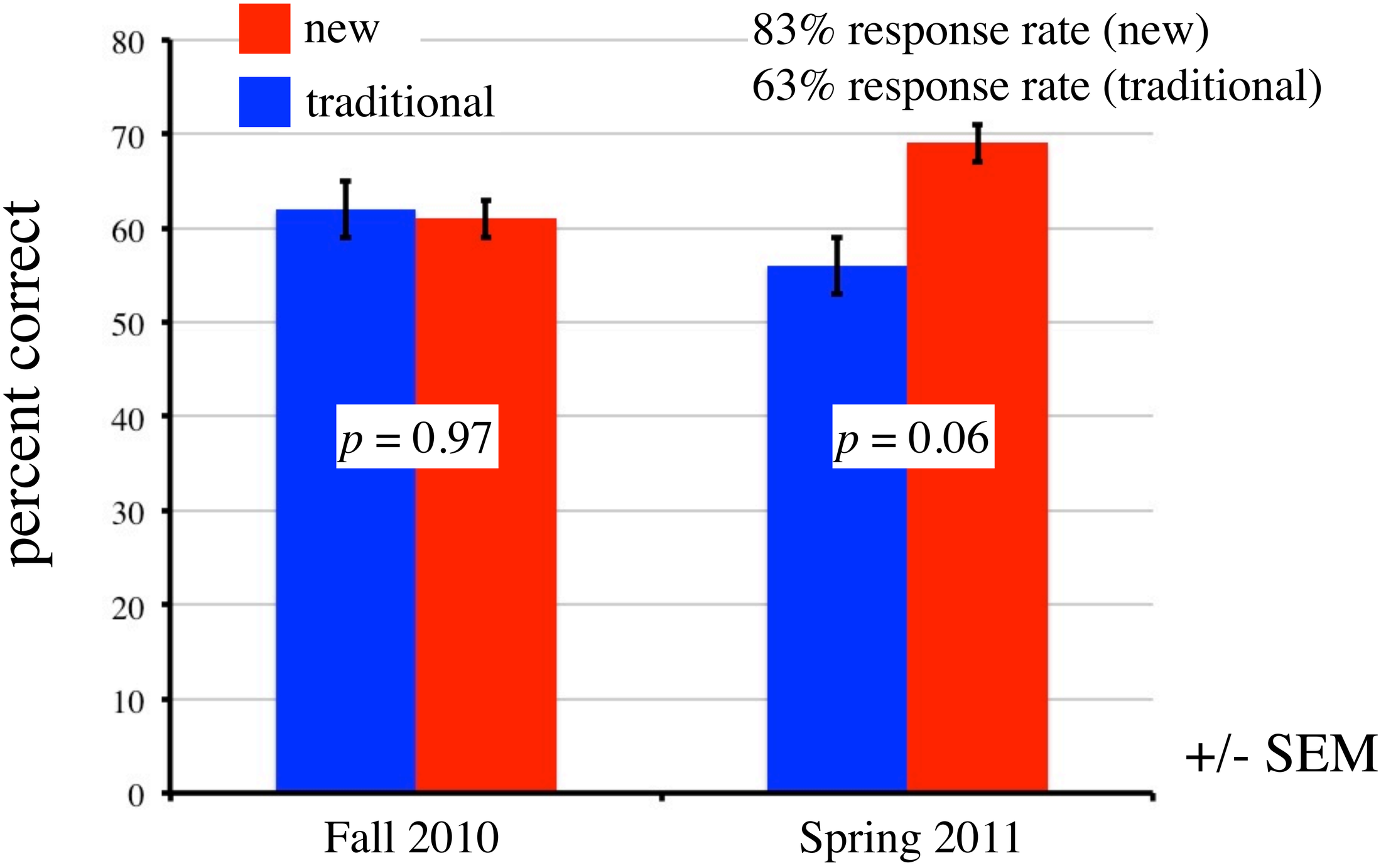
Did my students learn less content?

Student Content Assessment



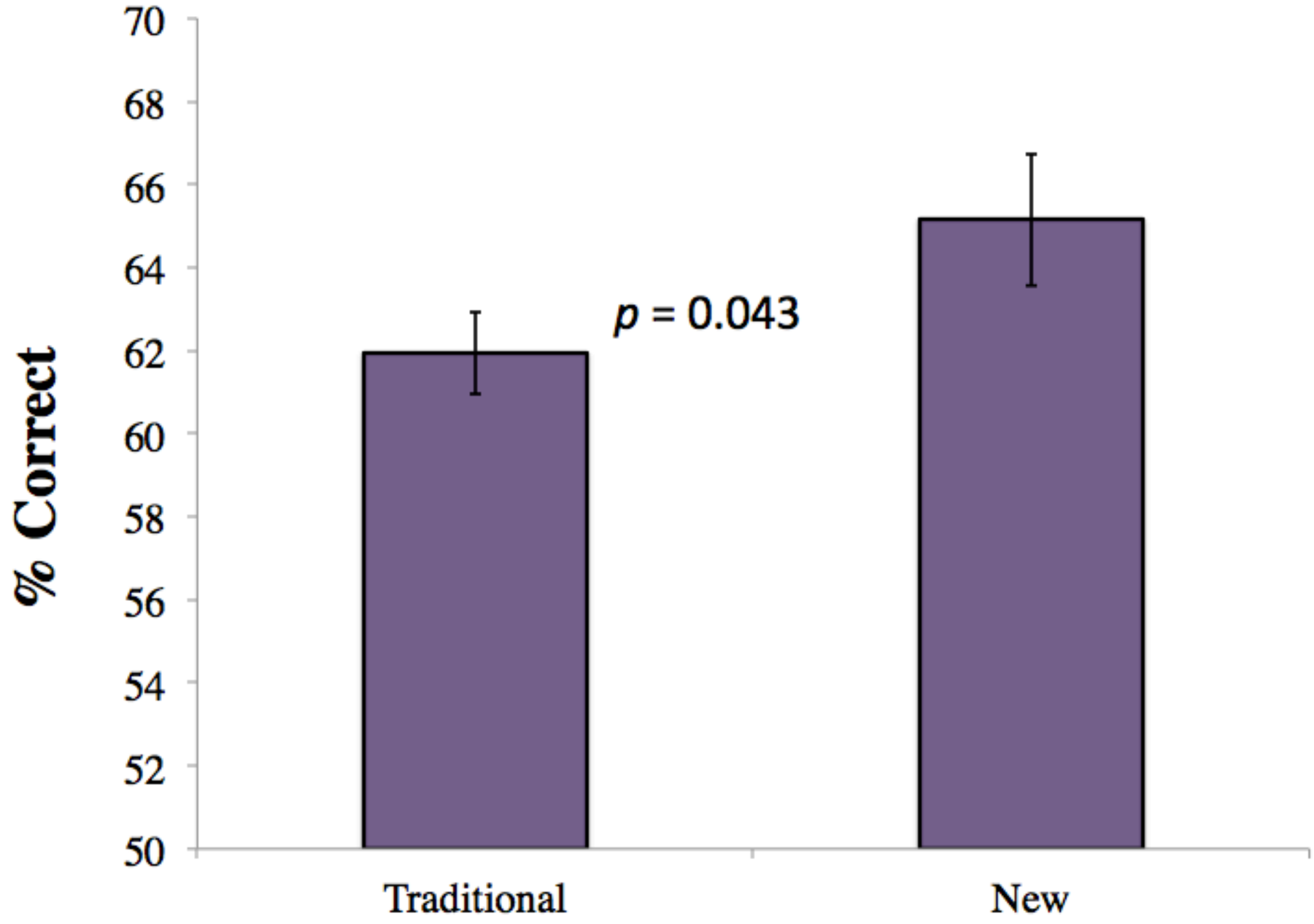
+/- SEM

Student Content Assessment

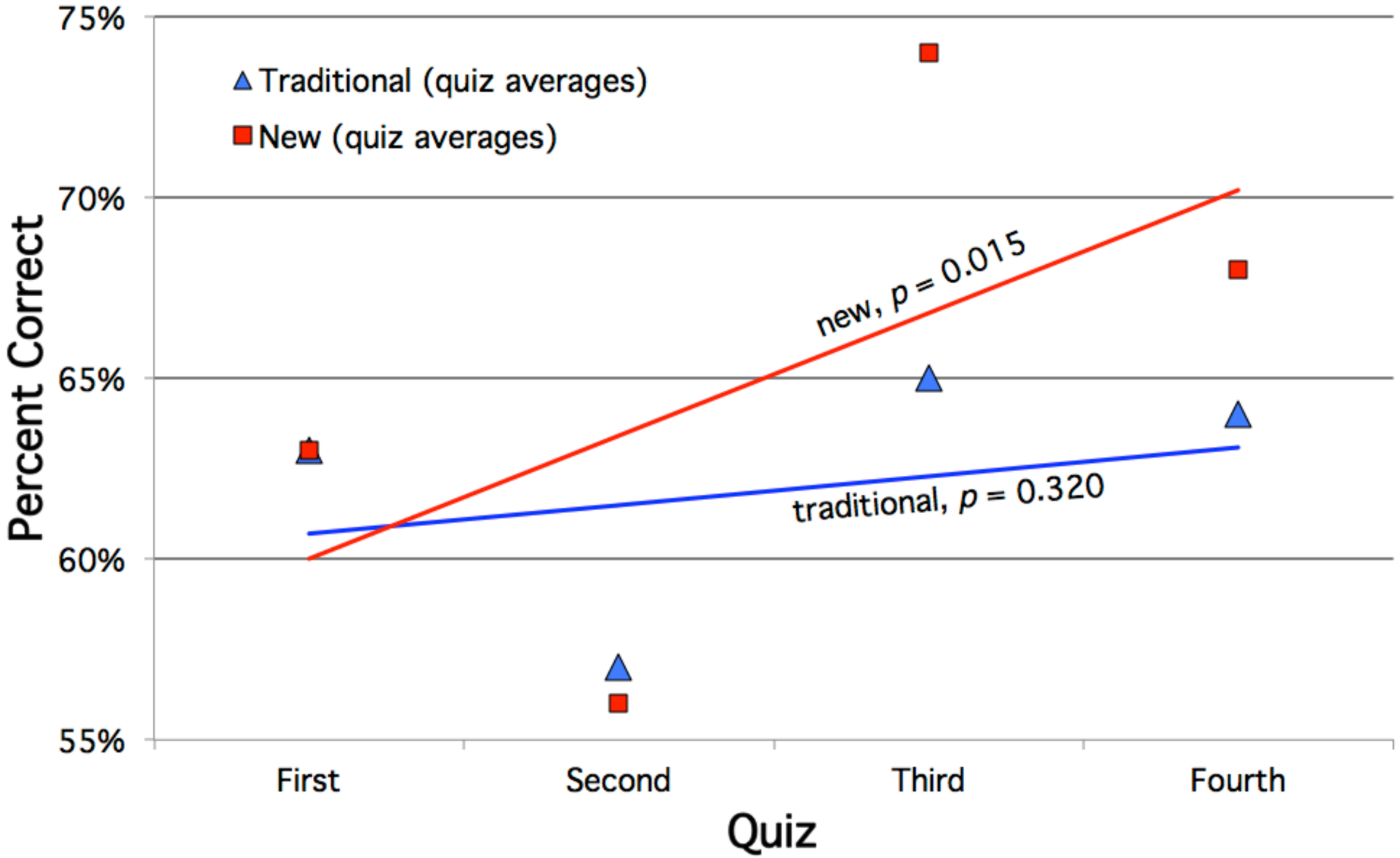


Can my students analyze data better?

Student Skills Assessment

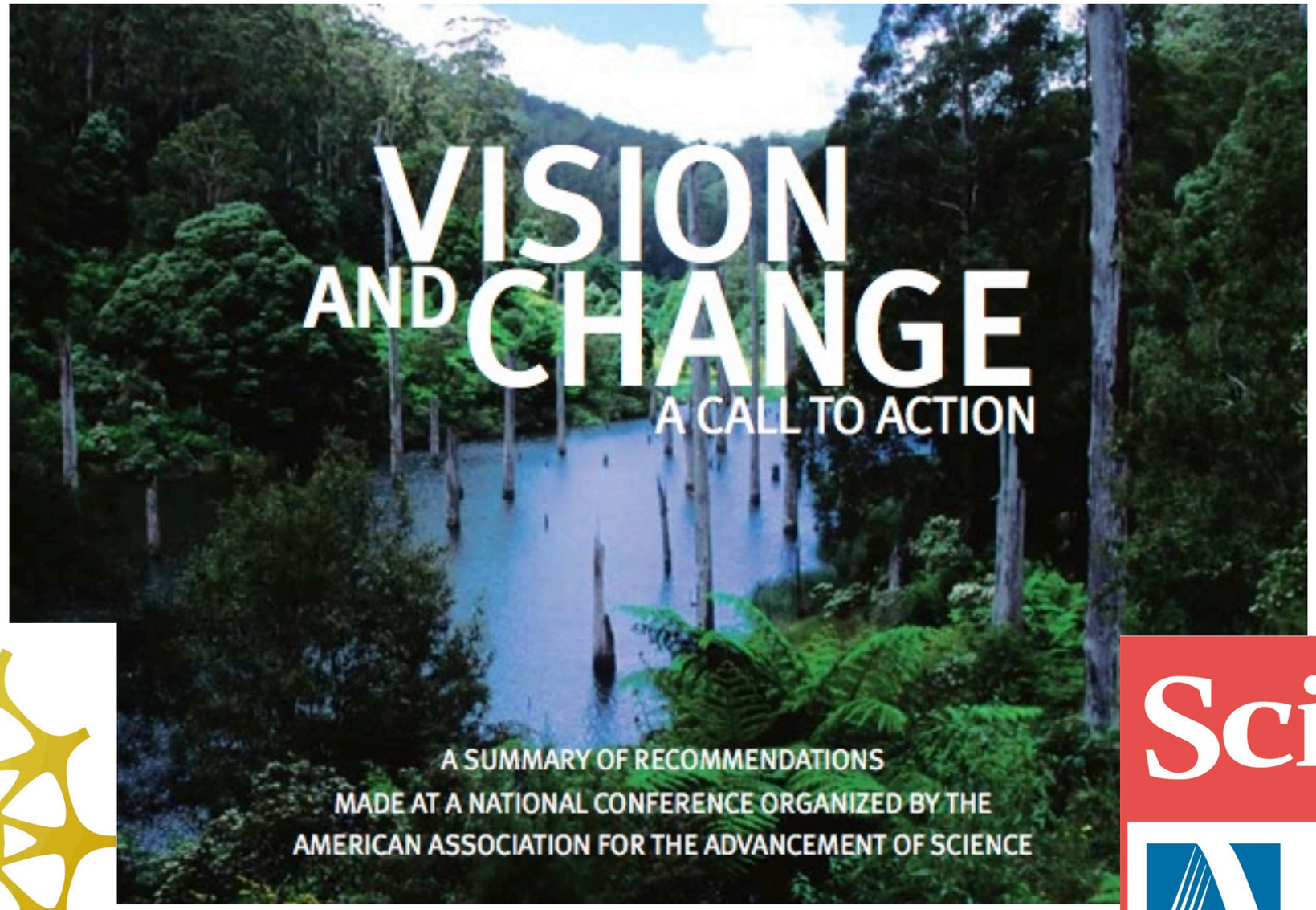


Student Skills Assessment



Why bother changing?

National Recognition of Need to Change



NSF

Science

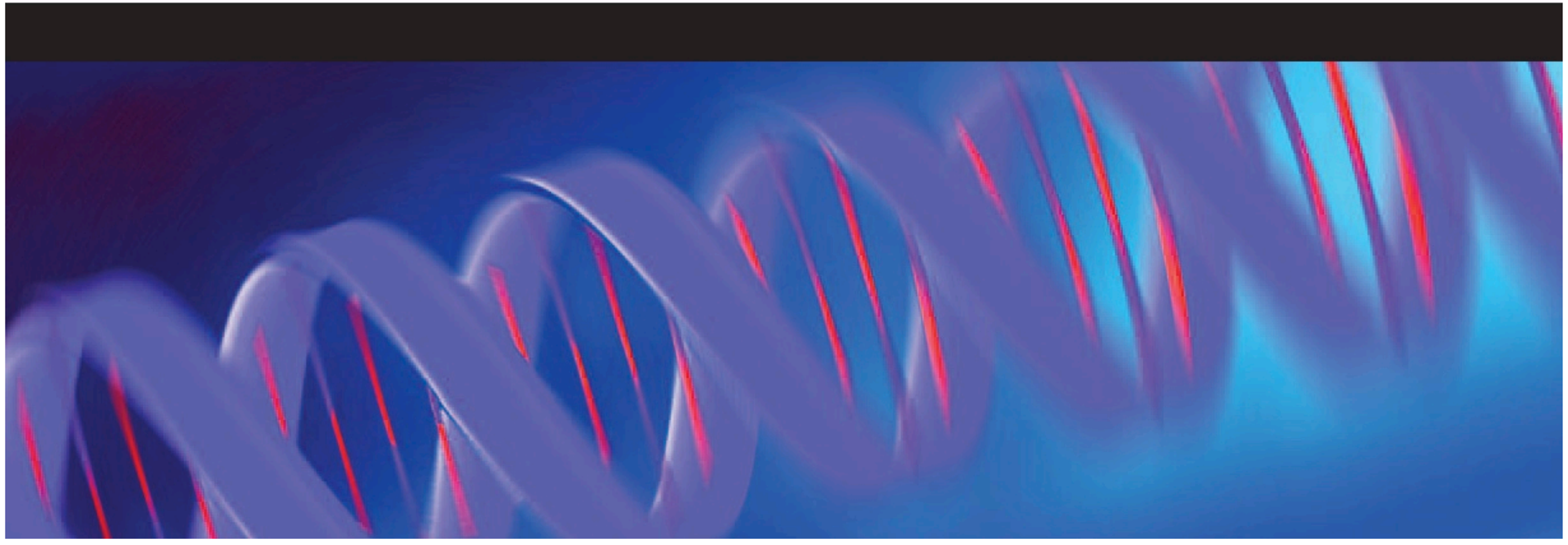
AAAS

AP Biology is Changing to Match Our Design

AP® BIOLOGY

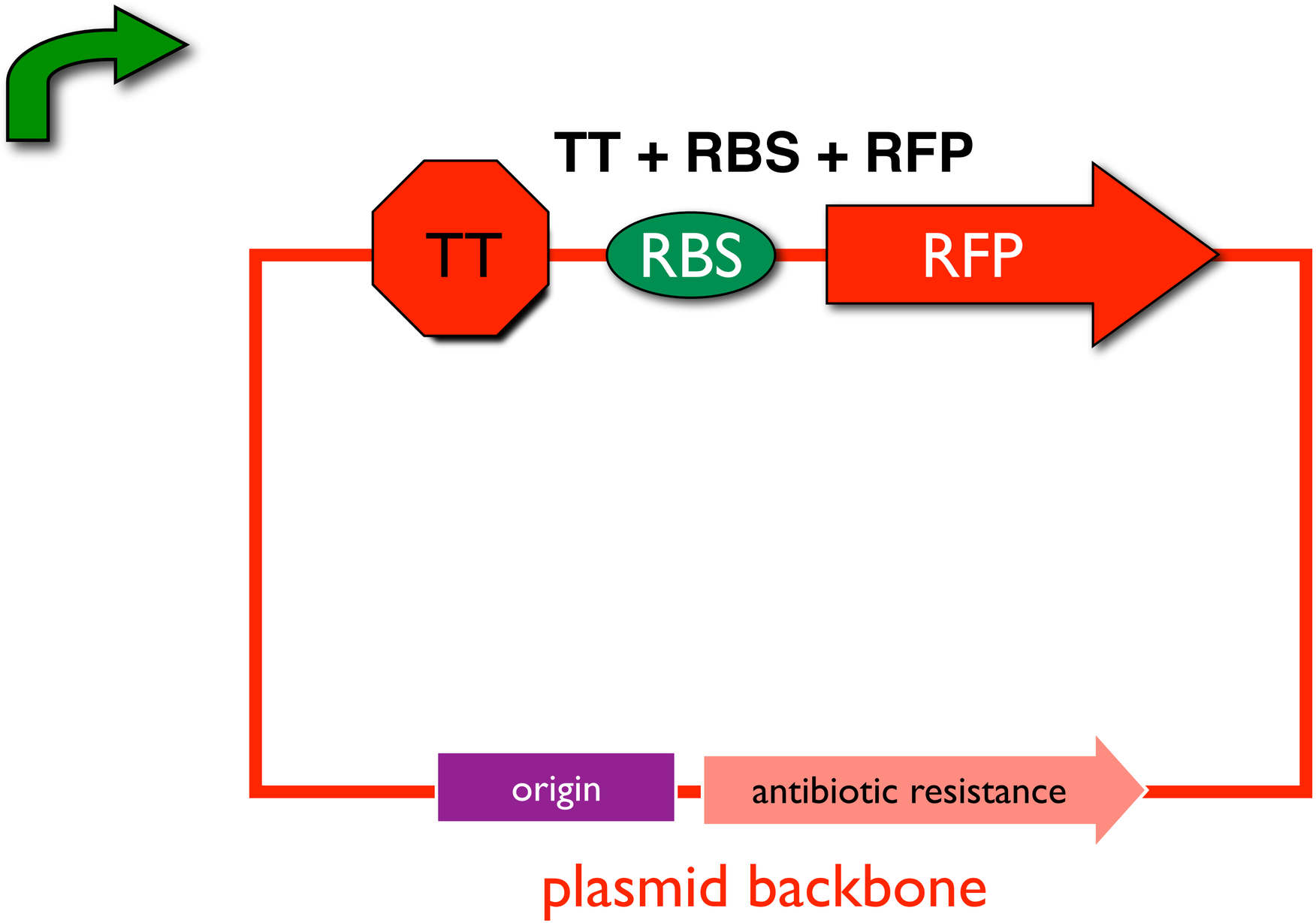
Curriculum Framework

2012–2013

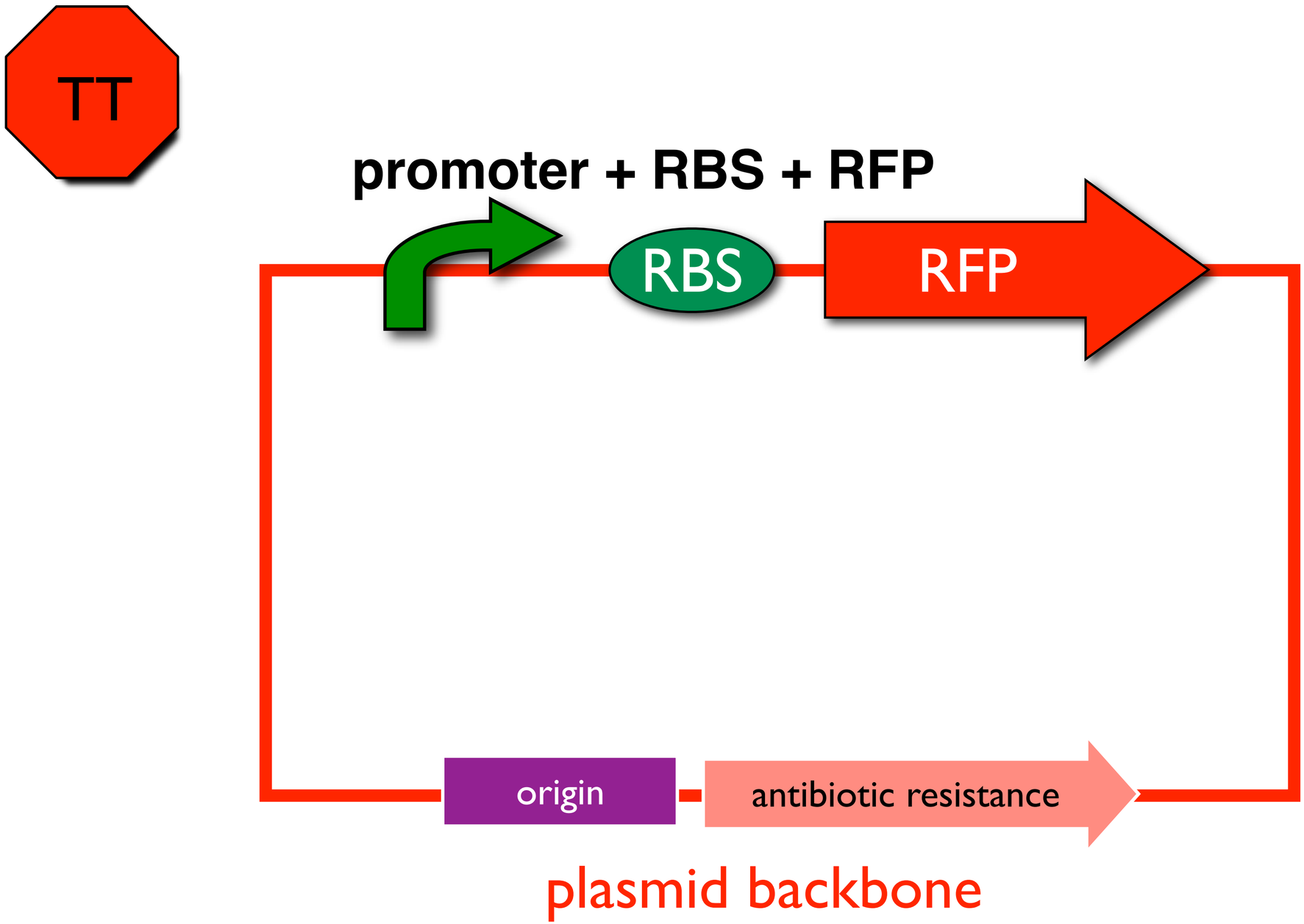


Can intro bio students do real synthetic biology research in 3 hour labs?

Golden Gate Assembly Method



Golden Gate Assembly Method



Eco RI

GAATTC
CTTAAG

palindrome

type II

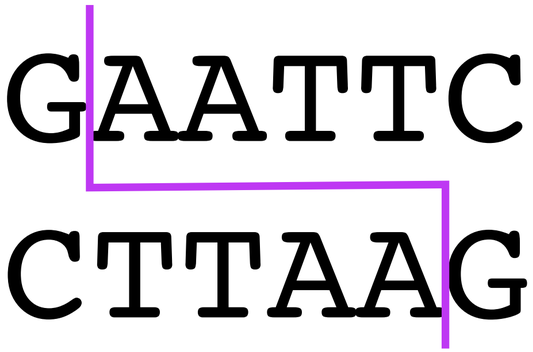
Eco RI

GAATTC
CTTAAG

palindrome

type II

Eco RI



type II

Eco RI

G AATTC

CTTAA G

type II

Bsa I

GAGACC

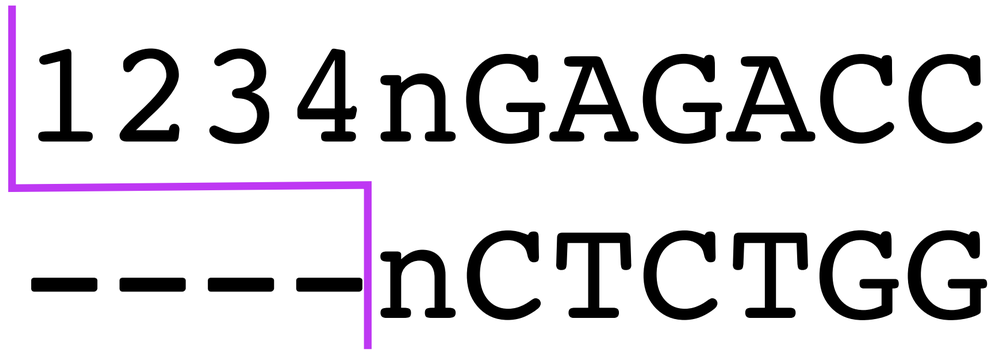
CTCTGG

G

not a palindrome

type IIs

Bsa I



type IIs

Bsa I

```
1234nGAGACC
----      nCTCTGG
```

type IIs

Bsa I

GGTCTCn----

CCAGAGn1234

type IIs

Bsa I

GGTCTCn ----

CCAGAGn1234

type IIs

Bsa I

cuts left

1234nGAGACC

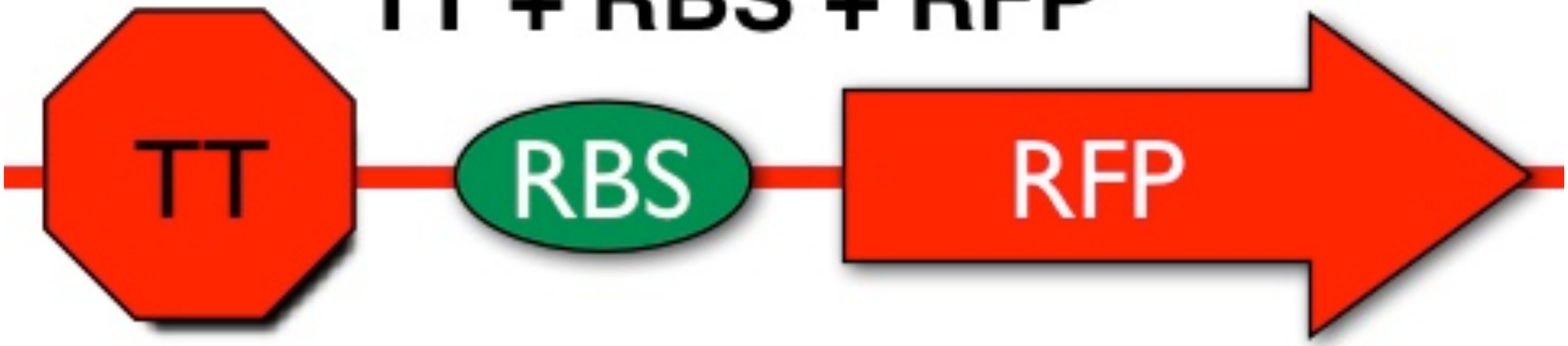
----nCTCTGG

GGTCTCn----

CCAGAGn1234

cuts right

TT + RBS + RFP

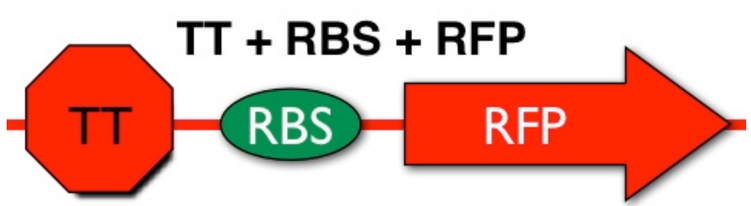


Bsa I

[redacted] **CGACtGAGACC(TT)GGTCTCaGCGG** [redacted]

[redacted] **GCTGaCTCTGG(TT)CCAGAGtCGCC** [redacted]

Bsa I



CGACtGAGACC(TT)GGTCTCa

aCTCTGG(TT)CCAGAGtCGCC

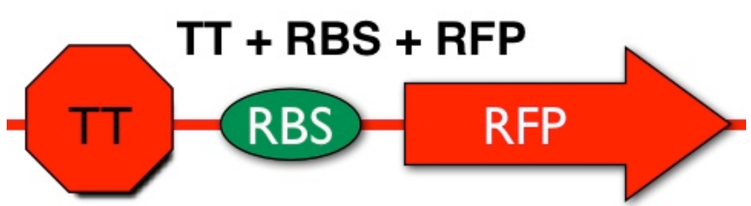
[redacted] GCTG

GCGG [redacted]

[redacted]

[redacted] CGACtGAGACC(TT)GGTCTCaGCGG [redacted]

[redacted] GCTGaCTCTGG(TT)CCAGAGtCGCC [redacted]



CGACtGAGACC(TT)GGTCTCa

aCTCTGG(TT)CCAGAGtCGCC

[redacted]

GCGG[redacted]

[redacted]GCTG

CGAC(promoter)

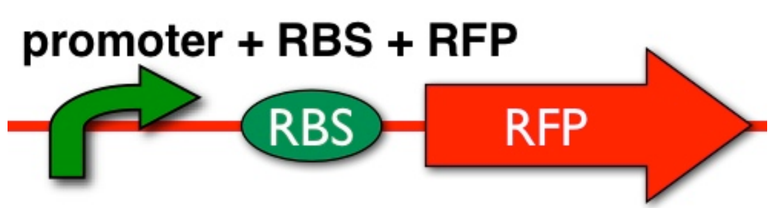
(promoter)CGCC

CGACtGAGACC(TT)GGTCTCa

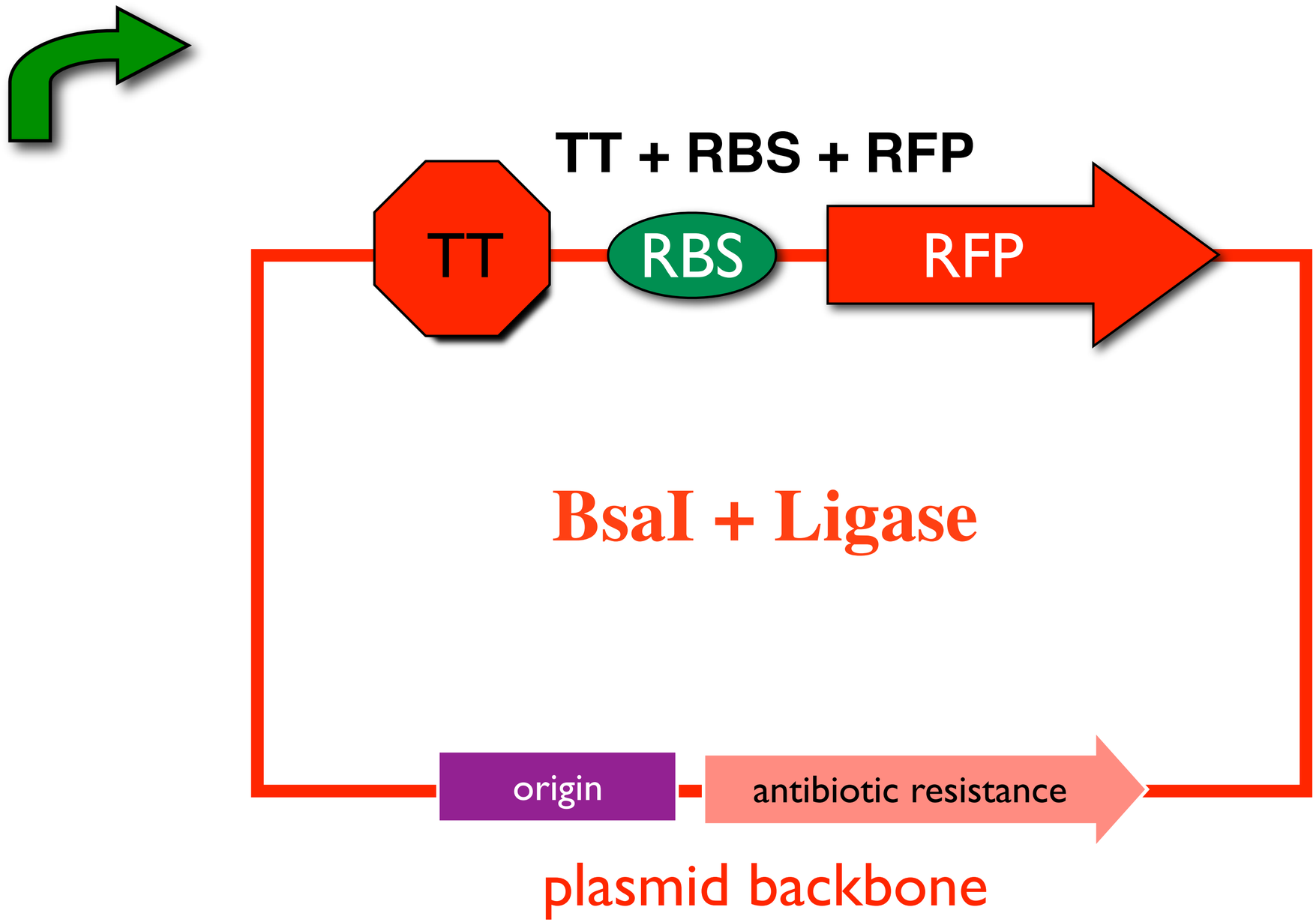
aCTCTGG(TT)CCAGAGtCGCC

[redacted] CGAC(promoter)GCGG [redacted]

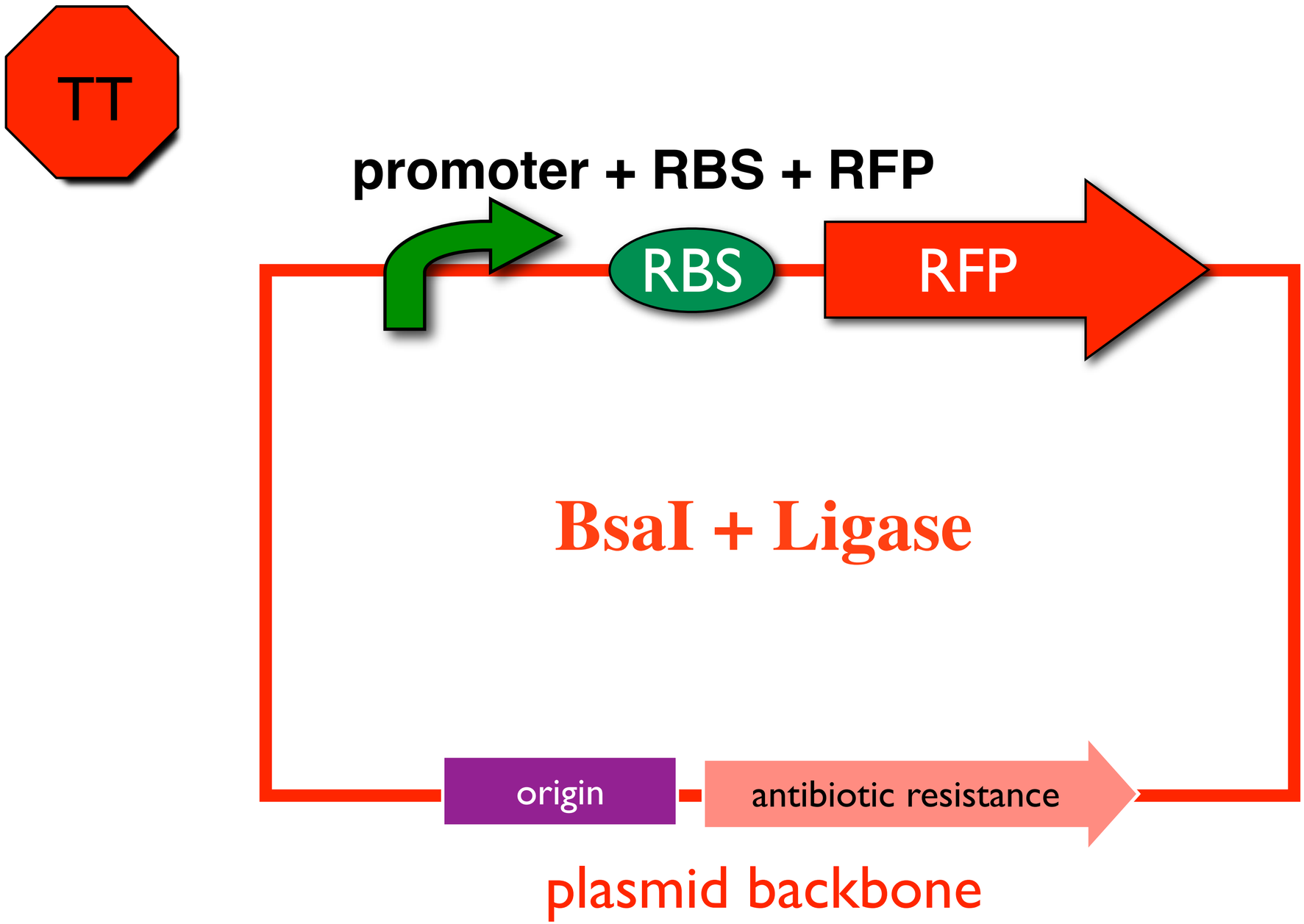
[redacted] GCTG(promoter)CGCC [redacted]



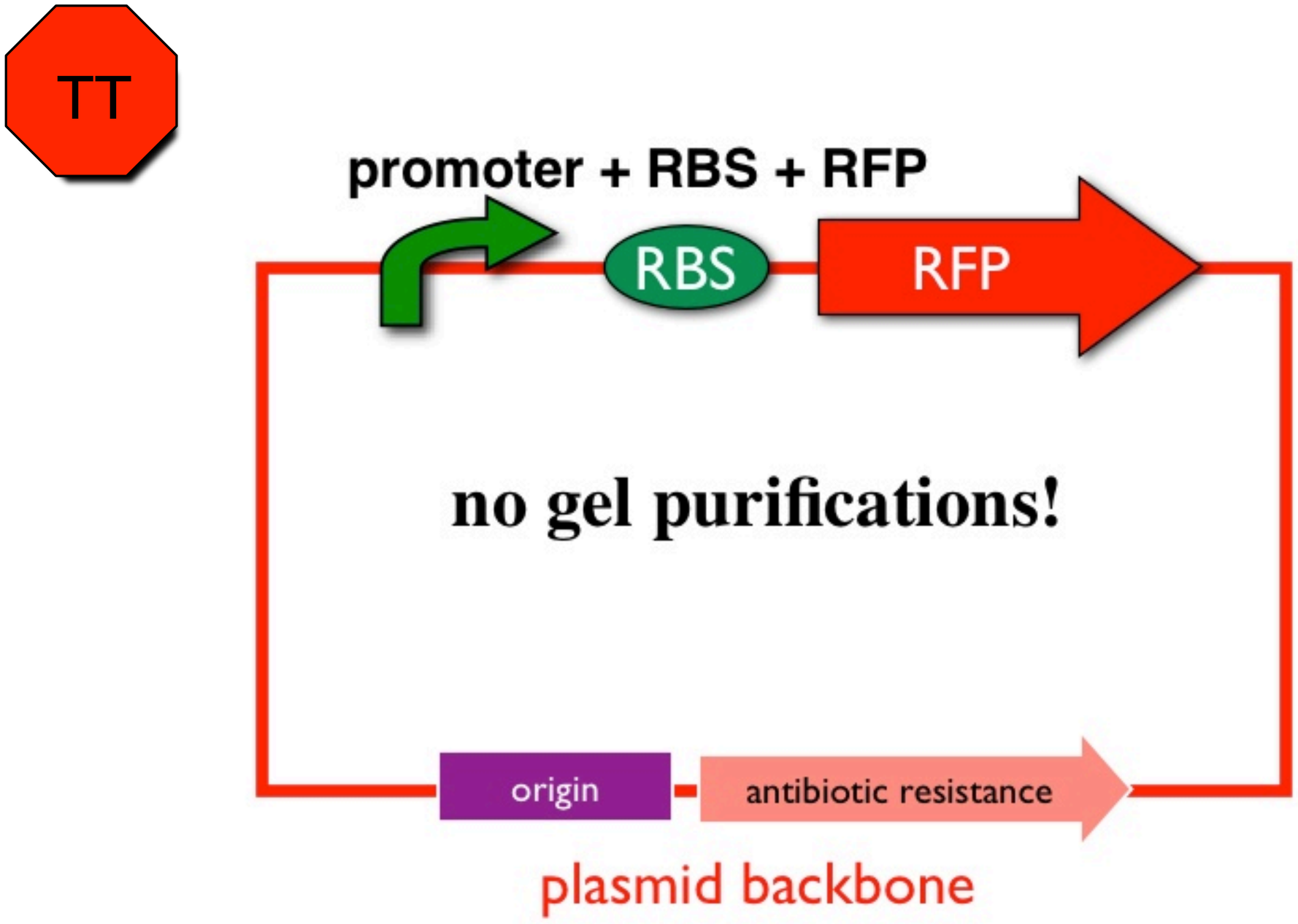
GGA Ligation Method



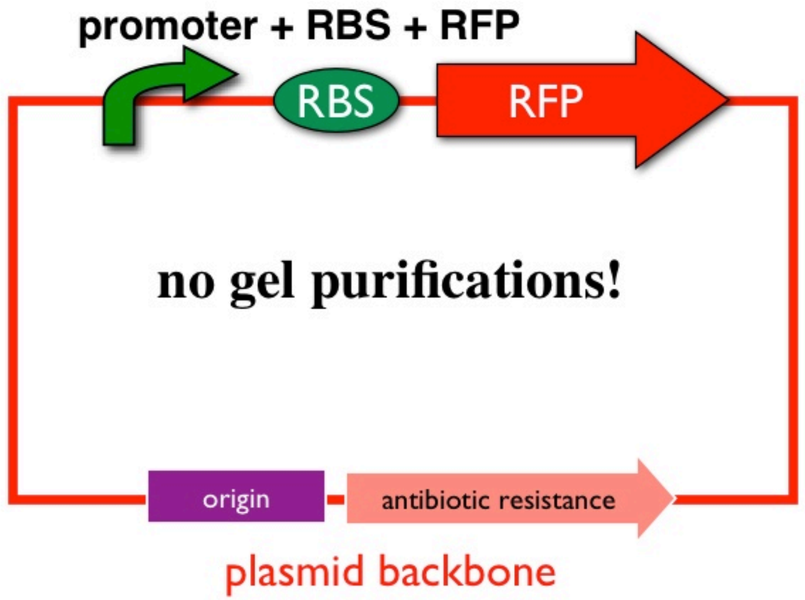
GGA Ligation Method

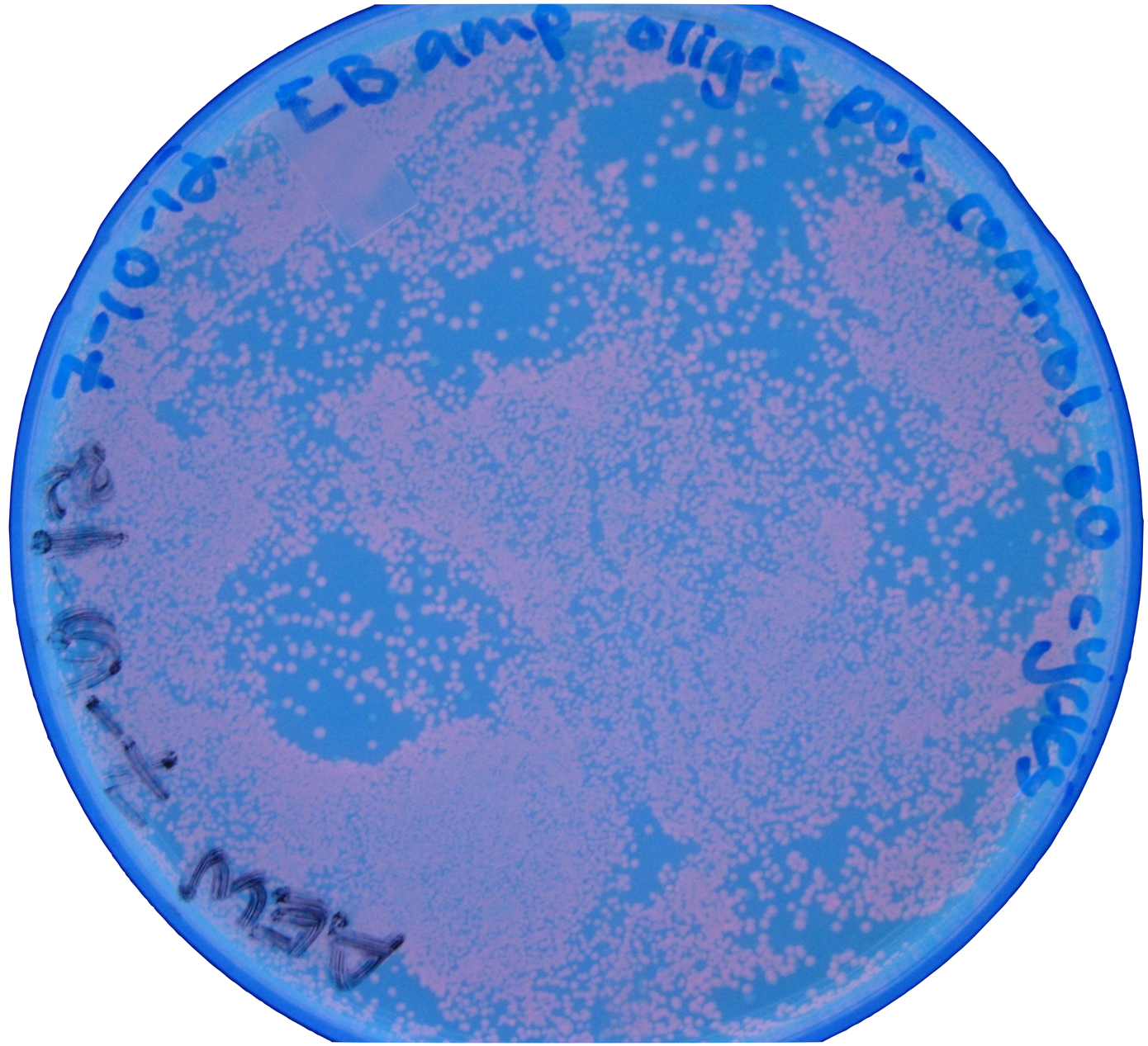


GGA Ligation Method



GGA Ligation Method





Registry of Functional Promoters

Registry of Standard Biological Parts

Go Search

non-wiki | Malcolm Campbell | My account | My requests | Log out

Campbell M Lab Parts

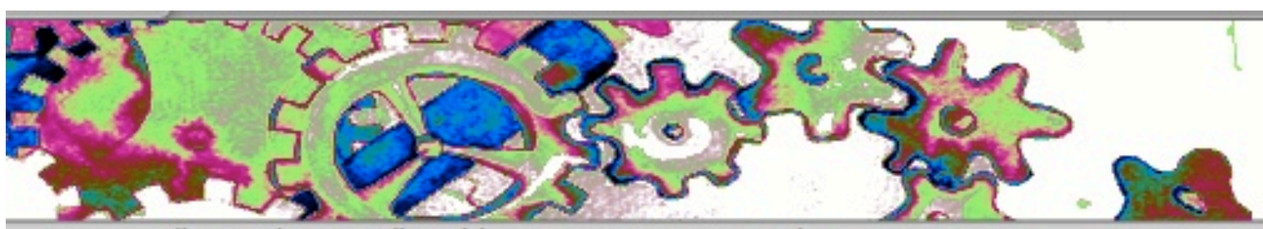
Favorite Campbell M Lab Parts *Edit*

-?-	Name	Type	Description	Designer	Length

Campbell M Lab Parts Sandbox *Edit*

-?-	Name	Type	Description	Designer	Length
	BBa_J100000	Coding	Cre with 8bp restriction sites and 1-Clause 2-SAT Problem Inserted	Eric Sawyer	1069
	BBa_J100001	Composite	pTet+RBS+Cre2SAT1Clause+pLpp+tRNA CCACU	Eric Sawyer	1357
	BBa_J100002	Composite	pTet+RBS+Cre2SAT1Clause+pLpp+tRNA CGGUC	Eric Sawyer	1357
	BBa_J100003	Generator	pTet+RBS+Cre2SAT1Clause	Eric Sawyer	1149
	BBa_J100004	Reporter	pTet+LoxP+RBS+RFP+LoxP	Eric Sawyer	870
	BBa_J100005	Other	Palindromic Stop Sequence	Eric Sawyer	221
	BBa_J100006	Intermediate	LoxP+Stop Sequence+LoxP	Eric Sawyer	305
	BBa_J100007	Intermediate	pLac+RBS+LoxP+Stop Sequence+LoxP	Eric Sawyer	533
	BBa_J100008	Composite	pLpp-tRNA CCACU-pLpp-tRNA CUAGU	Eric Sawyer	408
	BBa_J100009	Composite	pLpp-tRNA CCACU-pLpp-tRNA CGGUC	Eric Sawyer	408
	BBa_J100010	Composite	pLpp-tRNA CUAGU-pLpp-tRNA CGGUC	Eric Sawyer	408
	BBa_J100011	Composite	pLpp-tRNA CCACU-pLpp-tRNA CUAGU-pLpp-tRNA CGGUC	Eric Sawyer	616
	BBa_J100012	Intermediate	RBS-RFP-RBS	Eric Sawyer	747
	BBa_J100013	Coding	LuxI with 1 Clause 2-SAT Problem	Eric Sawyer	638
	BBa_J100014	Coding	LuxI with 2 Clause 2-SAT Problem	Eric Sawyer	652
	BBa_J100015	Composite	1 Clause 2-SAT Problem with Frameshifted LuxI and a GFP Reporter	Eric Sawyer	2757
	BBa_J100016	Composite	2 Clause 2-SAT Problem with Frameshifted LuxI and a GFP Reporter	Eric Sawyer	2771
	BBa_J100017	Composite	TT+pLux+RBS+LuxI(2-SAT 2 clause)+RBS+GFP+pLac+RBS+LuxR+tRNAs	Eric Sawyer	3395
	BBa_J100018	Protein_Domain	First Half of AspC gene	Catherine Doyle	448
	BBa_J100019	Protein_Domain	First half of ilvE gene	Julia Fearrington	457
	BBa_J100020	Protein_Domain	Second Half of AspC	Catherine Doyle	869
	BBa_J100021	Protein_Domain	First Half of PyrE	Catherine Doyle	488
	BBa_J100022	Protein_Domain	Second Half of PyrE	Catherine Doyle	280
	BBa_J100025	Protein_Domain	First half of CAT gene	James Harden	434
	BBa_J100026	Protein_Domain	second half ilvE gene	Julia Fearrington	574
	BBa_J100027	Protein_Domain	second half of TyrB	James Harden	288
	BBa_J100028	Other	placeholder insert for BsaI Golden Gate Assembly of promoter	Malcolm Campbell	877
	BBa_J100029	Regulatory	The promoter of rpoDPhs	Maggie Baay	76
	BBa_J100030	Regulatory	phoA is an inducible promoter induced by phosphate starvation.	Scott Hall	76
	BBa_J100031	Regulatory	Constitutive promoter C on Gene 1 of T7, transcribes RNA Pol.	Caroline Vrana	100
	BBa_J100032	Regulatory	proUP3 promoter	Molly Marshall	90
	BBa_J100033	Regulatory	dnakP1 promoter: Heat shock inducible	Chris Peek	101
	BBa_J100034	Regulatory	groE promoter	Margaret Stebbins	44
	BBa_J100036	Regulatory	Promoter induced by DNA damage	Erich Baker	52
	BBa_J100039	Regulatory	GalP1 Promoter-Induced By Galactose	Anaiah Toby	75
	BBa_J100040	Coding	LuxI with 3 clause 2-SAT problem	Eric Sawyer	684
	BBa_J100041	Composite	LuxI/GFP with 3 clause 2-SAT problem	Eric Sawyer	2803
	BBa_J100042	Coding	LuxI with 3 clause 3-SAT problem	Eric Sawyer	702
	BBa_J100043	Composite	LuxI/GFP with 3 clause 3-SAT problem	Eric Sawyer	2821
	BBa_J100044	Coding	LuxI with 4 clause 2-SAT problem	Eric Sawyer	704
	BBa_J100045	Composite	LuxI/GFP with 4 clause 2-SAT problem	Eric Sawyer	2823
	BBa_J100046	RNA	lpp+tRNA CCAUC (10 bp anticodon loop)	Eric Sawyer	201
	BBa_J100047	Protein_Domain	TyrB2	Julia Fearrington	
	BBa_J100048	Protein_Domain	TyrB1	Julia Fearrington	930
	BBa_K091231	Composite	LuxR producer and XOR gate	Malcolm Campbell	2772
	BBa_K091232	Composite	LuxR producer and RFP(rev) + RBS(rev) + pLux (for)	Malcolm Campbell	1916

Student Sample



Registry of Standard Biological Parts

Go Search

page discussion edit history move watch Macampbell My account My requests Log out

BBa J100033 Main Page Part Design Physical DNA Hard Information Experience Tools

Part:BBa_J100033

Designed by Chris Peek Group: Campbell_M_Lab (2011-09-01)

Regulatory

DNA Planning

Experience:

Get This Part

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

Format: Subparts | Ruler | SS | **DS** **Search:** **Length: 101 bp** **Context: Part only** Get selected sequence

```
      1          11         21         31         41         51         61         71         81         91

1     aaatttctgc gcaaaagcac aaaaaatttt tgcatctccc ccttgatgac gtggtttacg accccattta gtagtcaacc gcagtgagtg agtctgcaaa
      tttaaagacg cgttttcgtg ttttttaaaa acgtagaggg ggaactactg caccaaatgc tggggtaaat catcagttgg cgtcactcac tcagacgttt

101   a
      t
```

Assembly Compatibility: 10 12 21 23 25

Student Sample

Registry of Standard Biological Parts

Go Search

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BBa J100033 Main Page Part Design Physical DNA Hard Information Experience Tools

Part:BBa_J100033:Experience

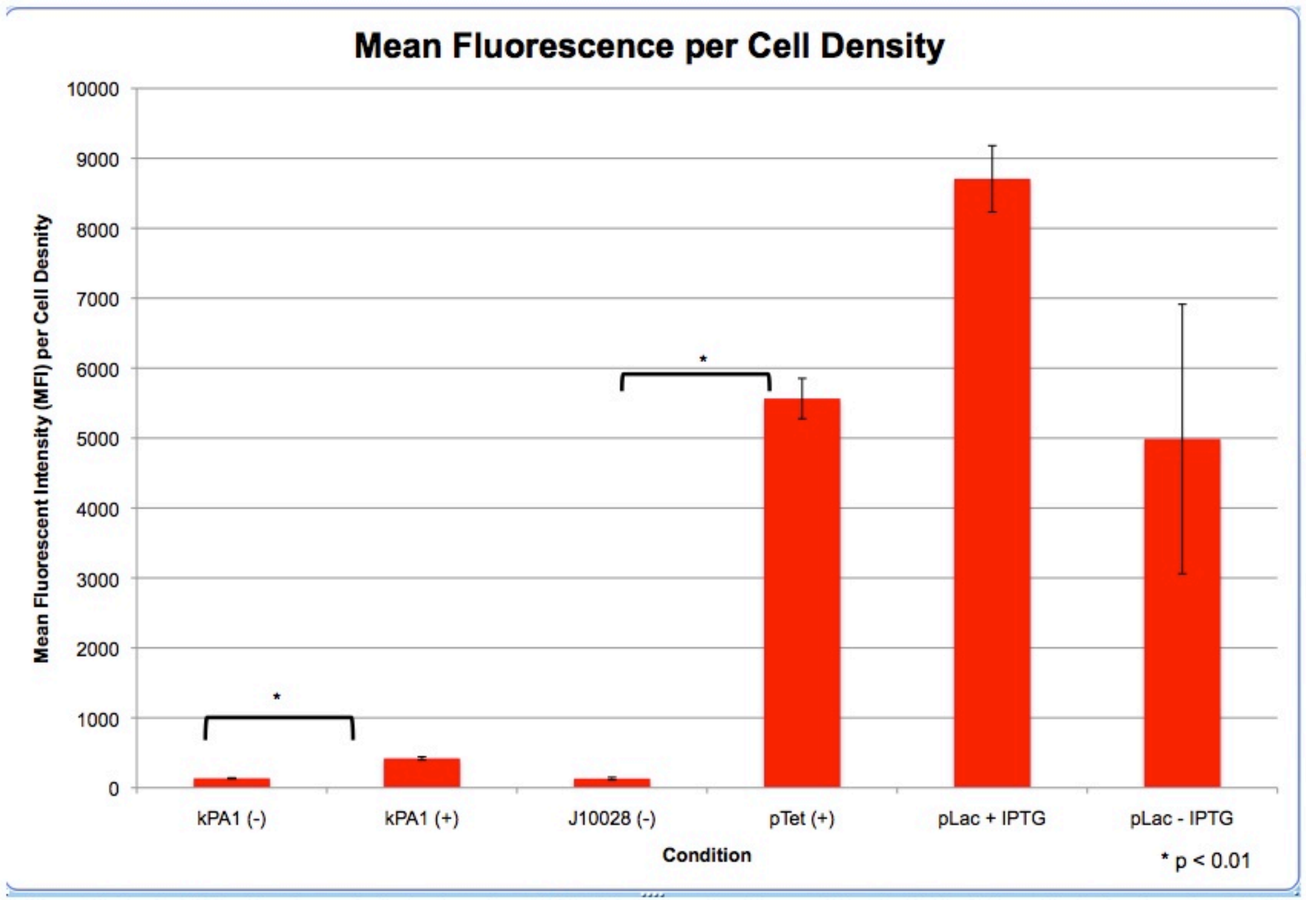
Designed by Chris Peek Group: Campbell_M_Lab (2011-09-01)

Regulatory

DNA Planning
Experience:
Get This Part

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 [edit]



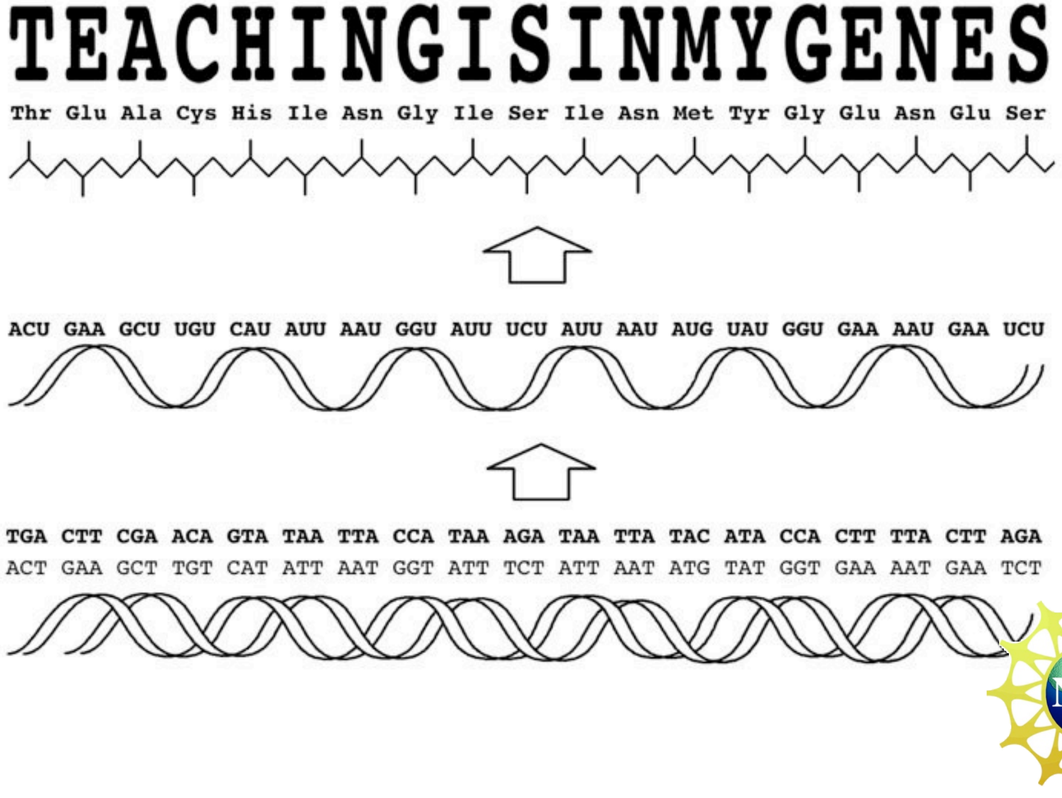
A: Experimental: cells containing dnaKP1 without heat shock (incubated at 37°C) B: Experimental: cells containing dnaKP1 with heat shock (incubated at 40°C) C: Negative control: part j100028 without pTet promoter D: Positive control: part j100028 with pTet promoter (always on) E: pLac promoter (part j715039) with inducer (IPTG) F: pLac

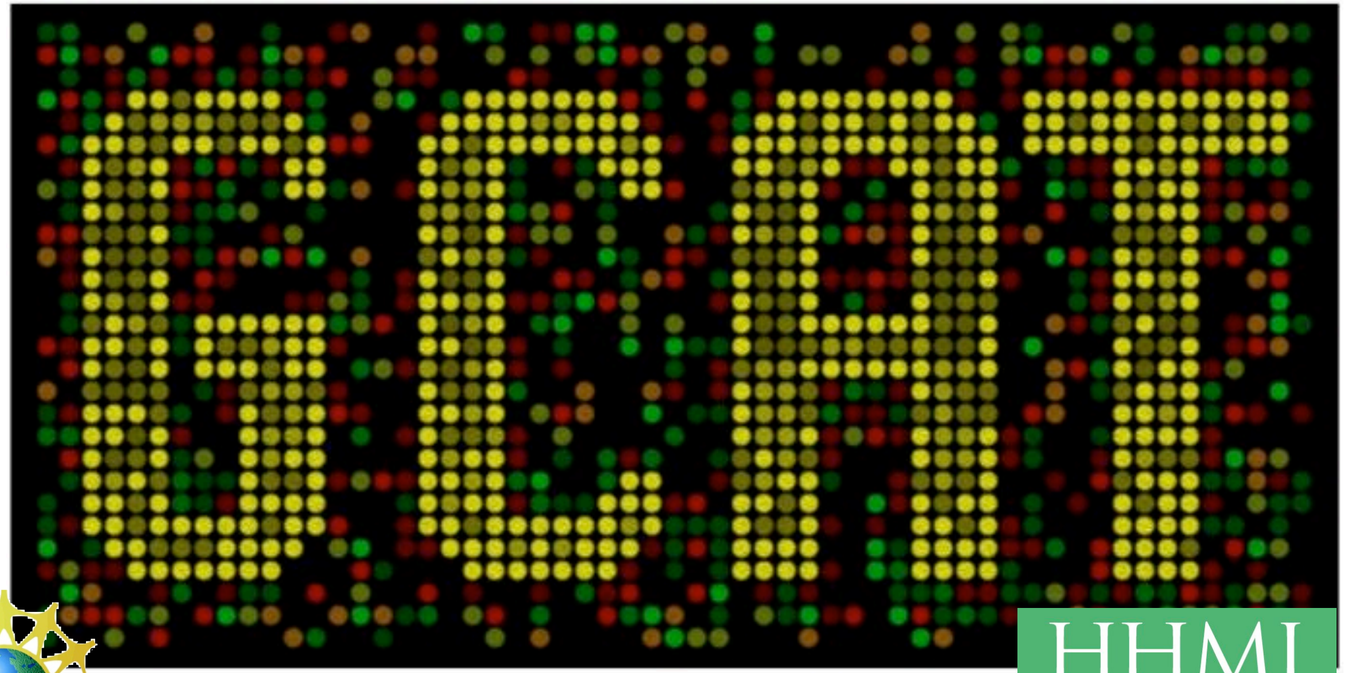
GCAT Faculty Workshop
Synthetic Biology

15 pairs of faculty

1 Bio + 1 Other

NSF & HHMI





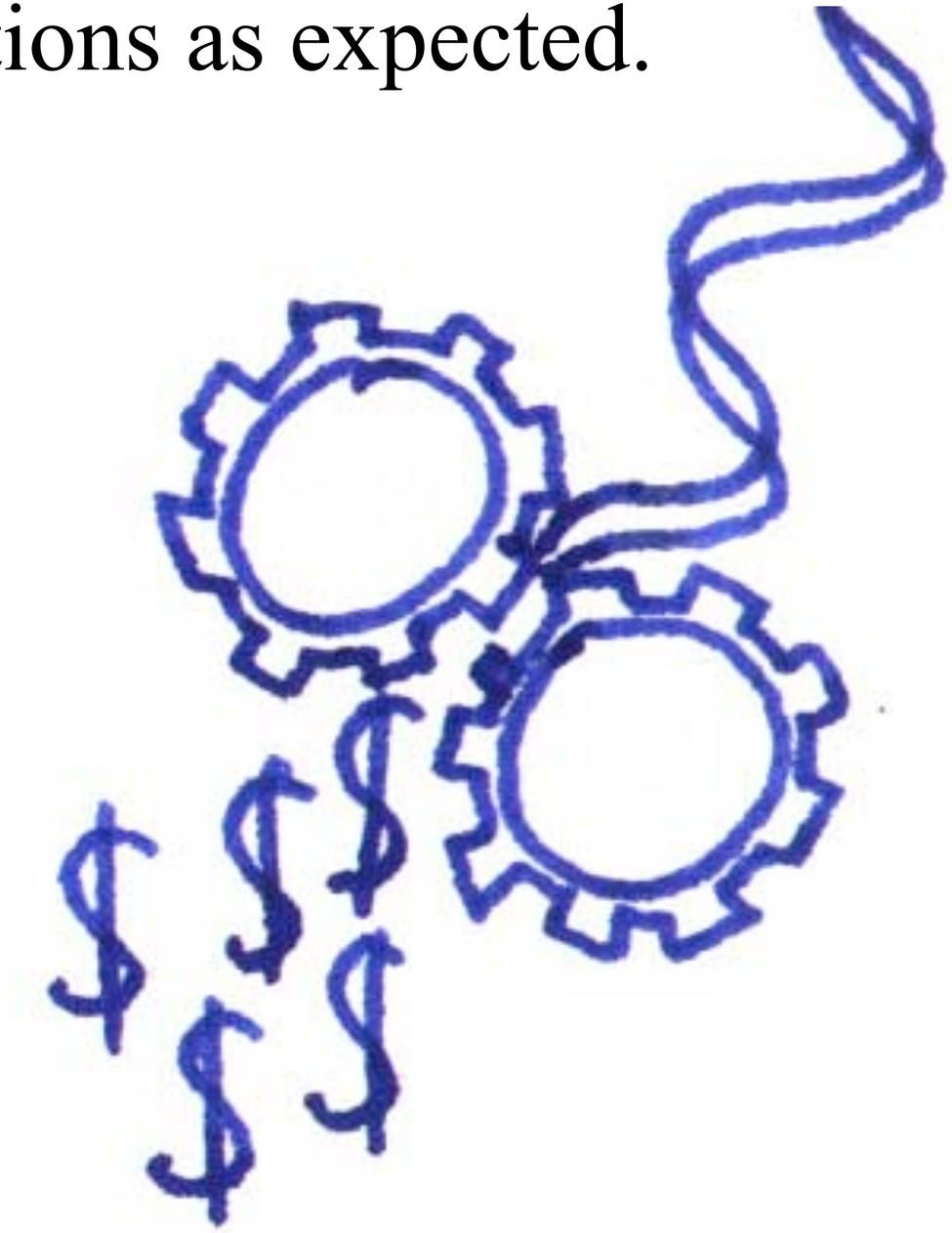
NSF

HHMI
HOWARD HUGHES MEDICAL INSTITUTE

Synthetic Biology Research at Davidson College

Synthetic Biology: Win-Win

Win #1: your design functions as expected.



Synthetic Biology: Win-Win

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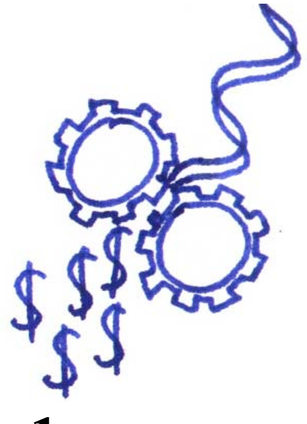
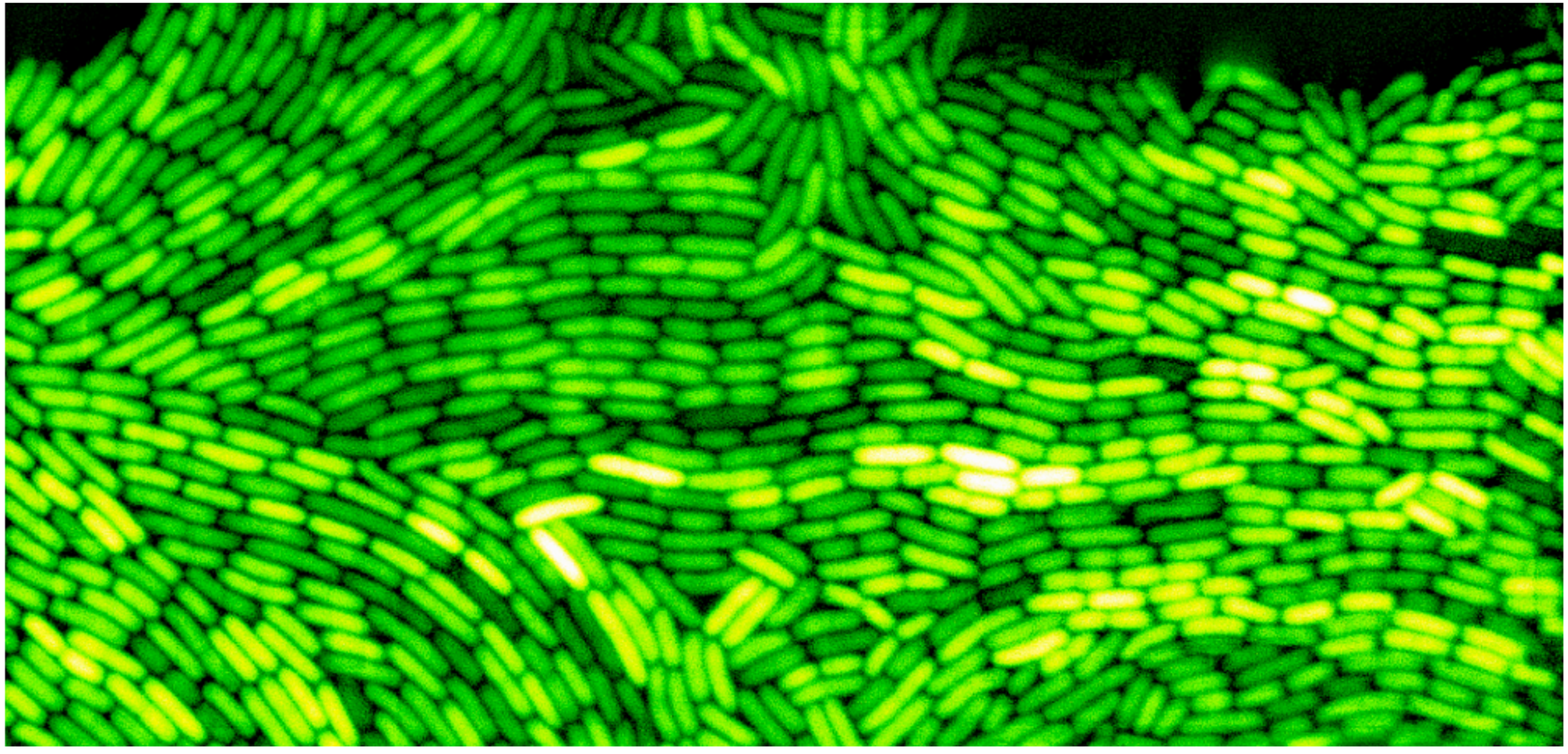
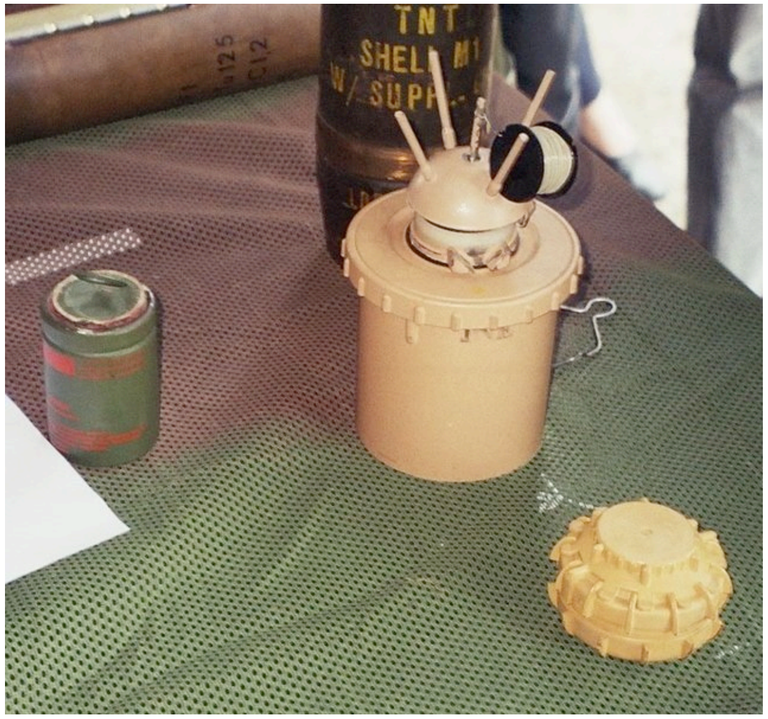


Win #2: your design fails but you uncover basic biology

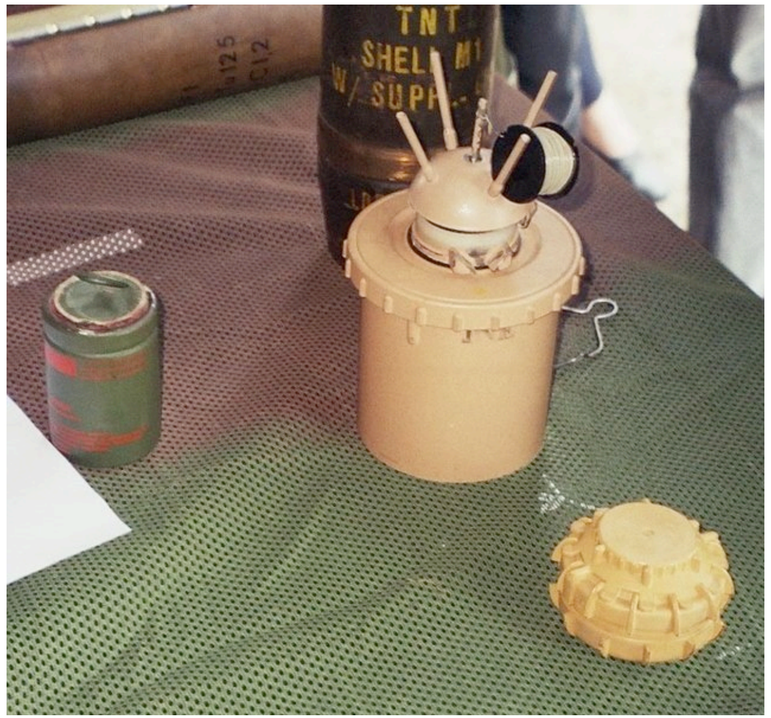


Real World Applications of Synthetic Biology

Land Mine Detection



Land Mine Detection



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*

Synthetic Biology
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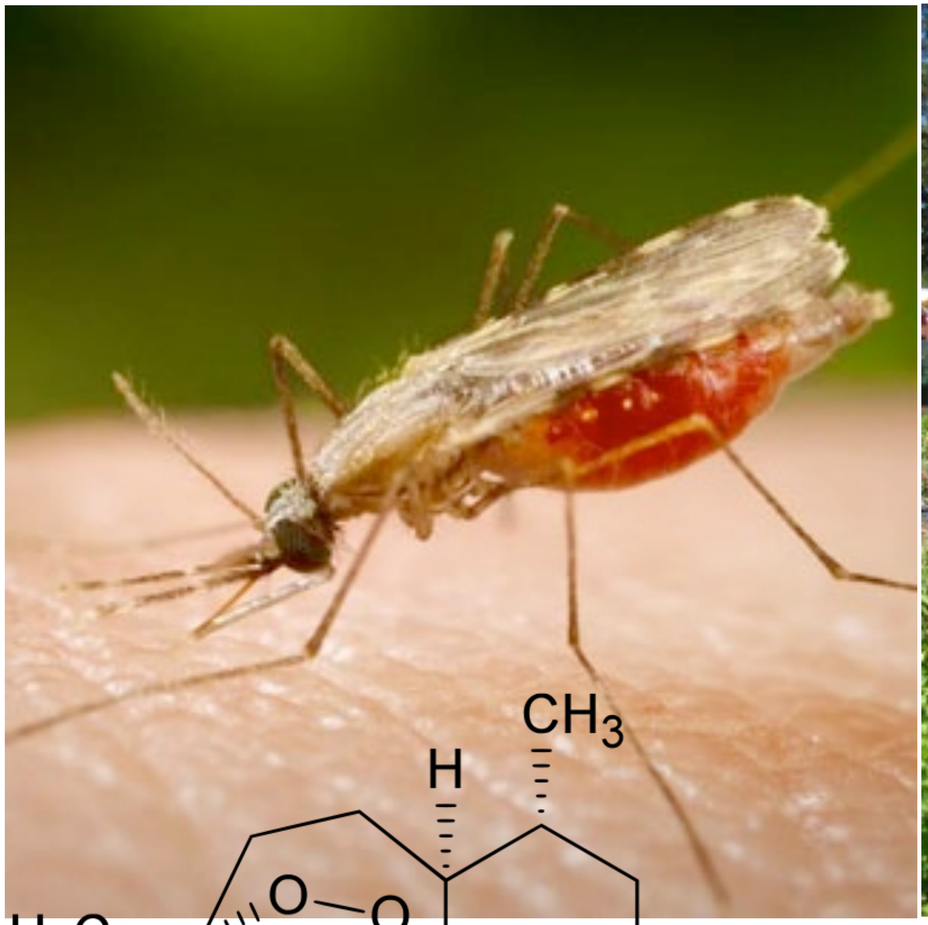
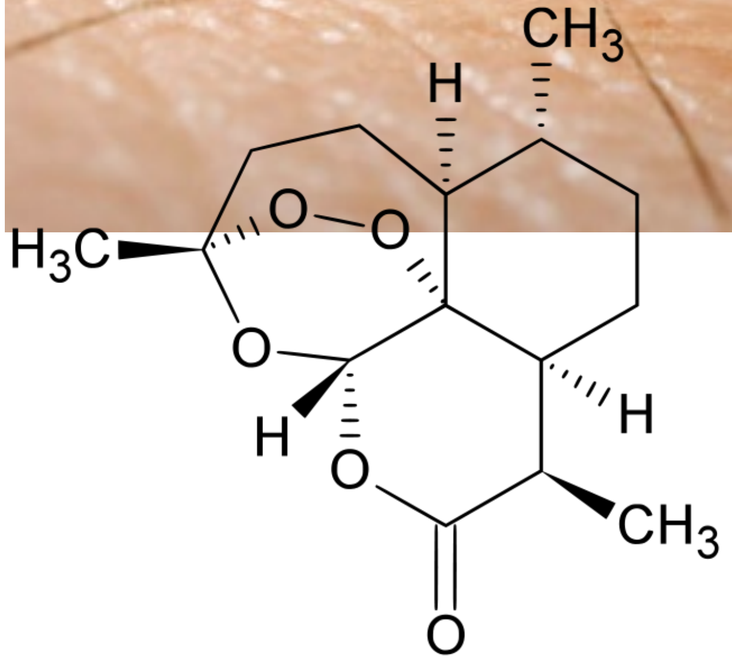
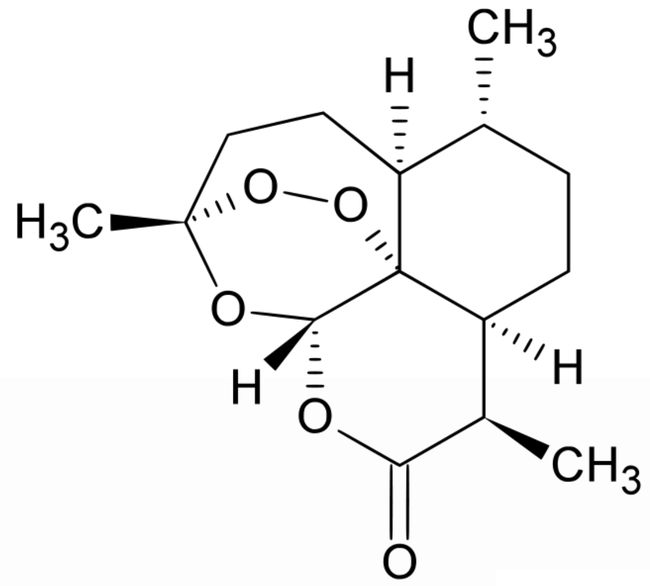
Production of Medicines



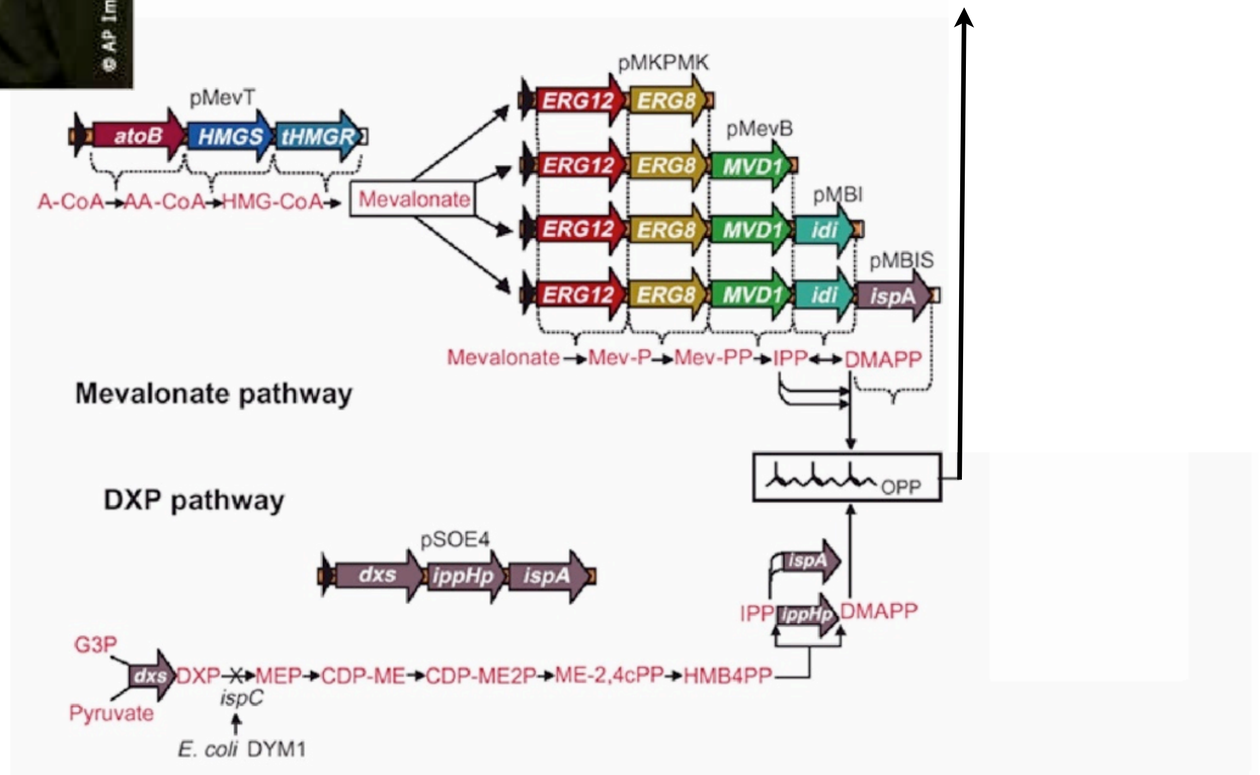


$1 per pill

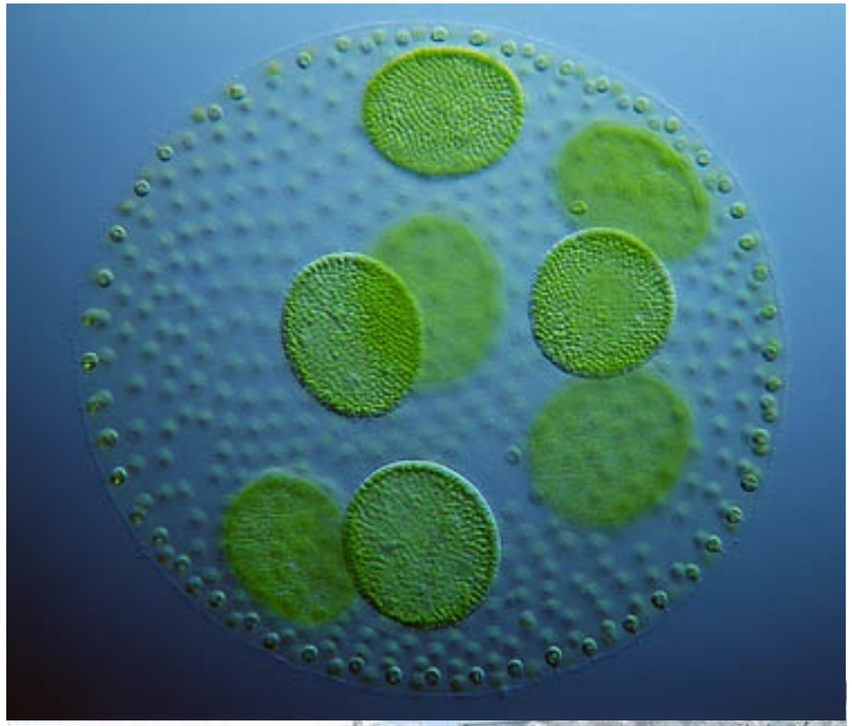
Production of Medicines



10¢ per pill



Biofuels from Algae



CO_2-neutral

1,000,000 gallons in 2008

Laurie Heyer, Todd Eckdahl & Jeff Poet

DAVIDSON

Discover Gold WESTERN

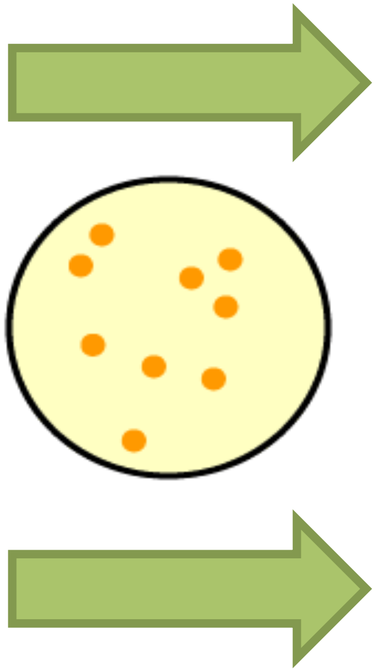
Building Bacterial Computers

Can we build a bacterial cryptographic hash function?

What is a hash function?

HGTf34$2

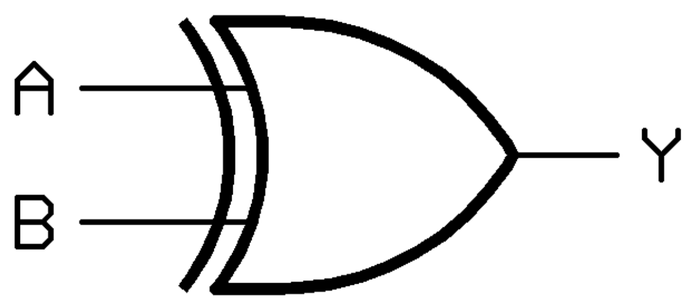
Can Bacteria Perform a Hash Function?



HGTf34$2

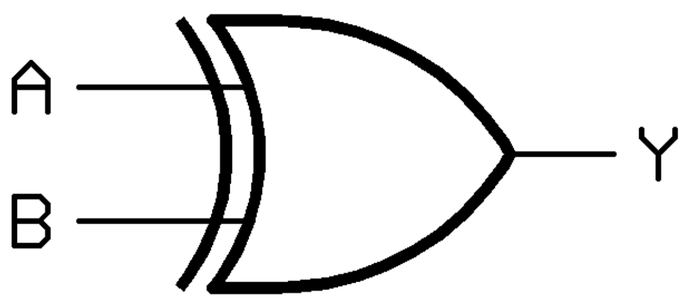
Use XOR Logic Gate for Hash Function

Input 1	Input 2	Output
0	0	0
0	1	1
1	0	1
1	1	0



Use XOR Logic Gate for Hash Function

Input 1	Input 2	Output
0	0	0
0	1	1
1	0	1
1	1	0



Use XOR Logic Gate for Hash Function

Input 1	Input 2	Output
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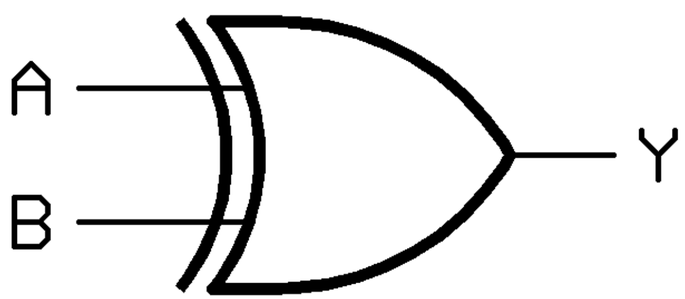
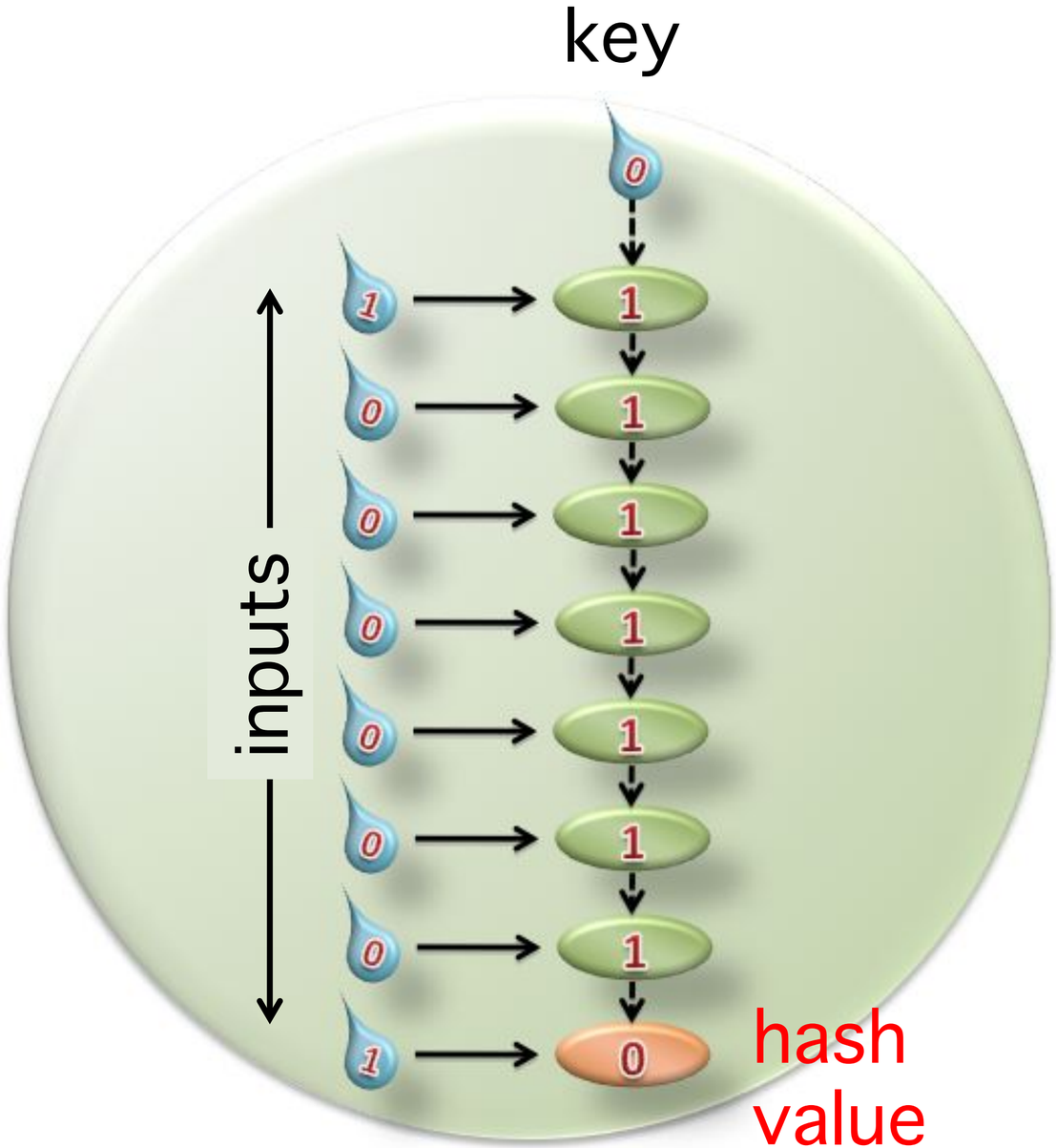


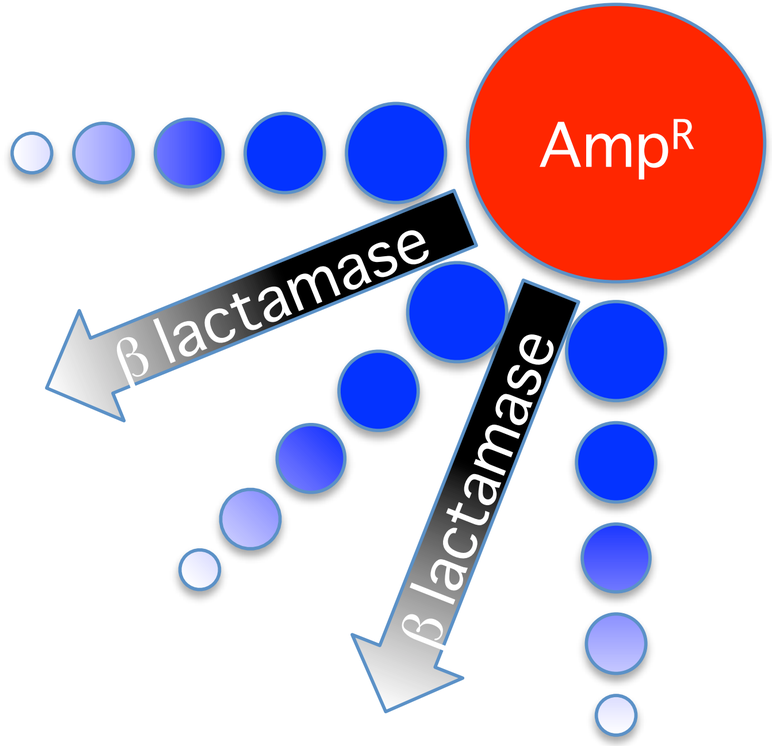
Design Linear Bacterial Hash Function

CAB = 010000001

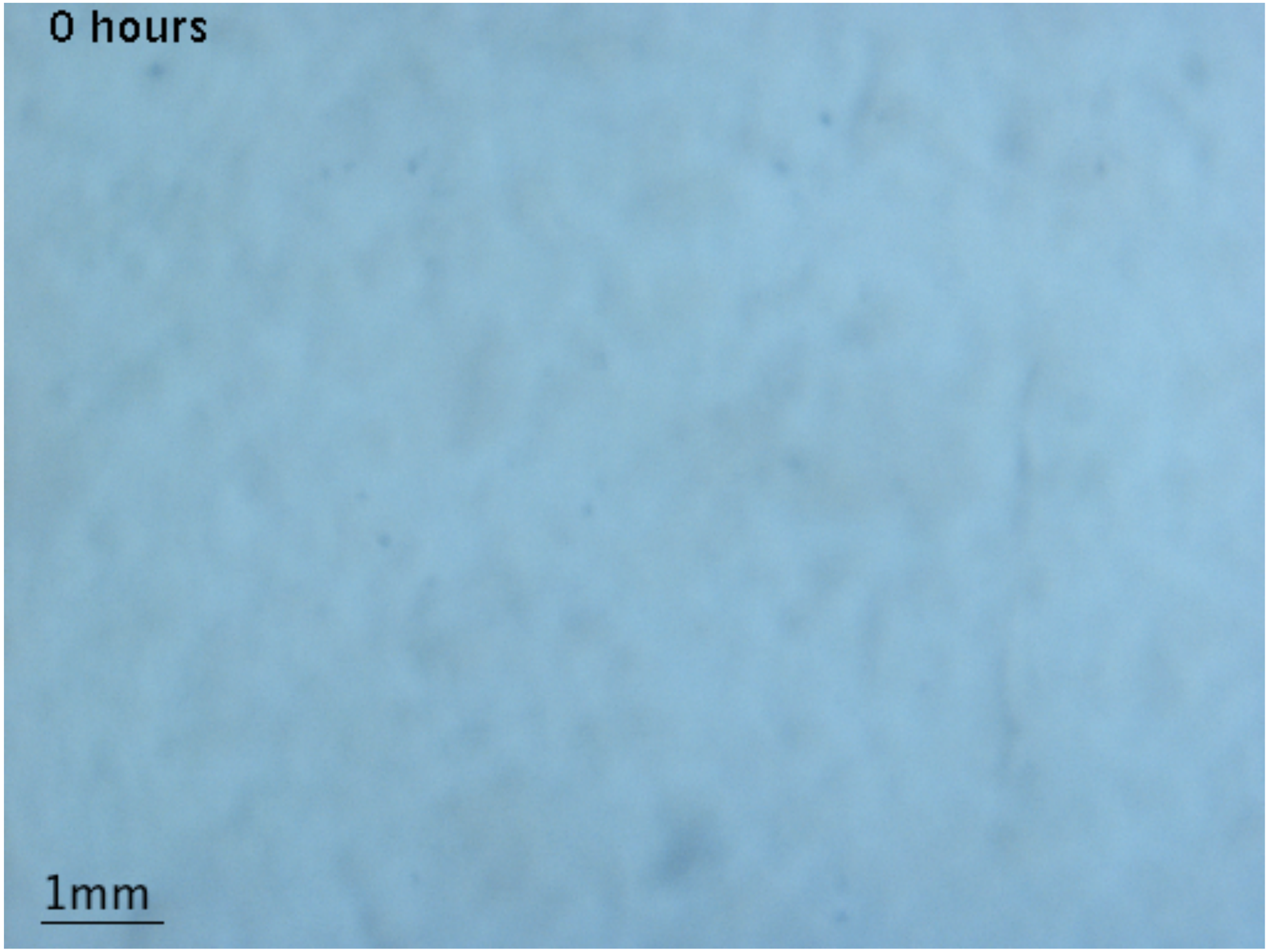
HASH VALUE = 0



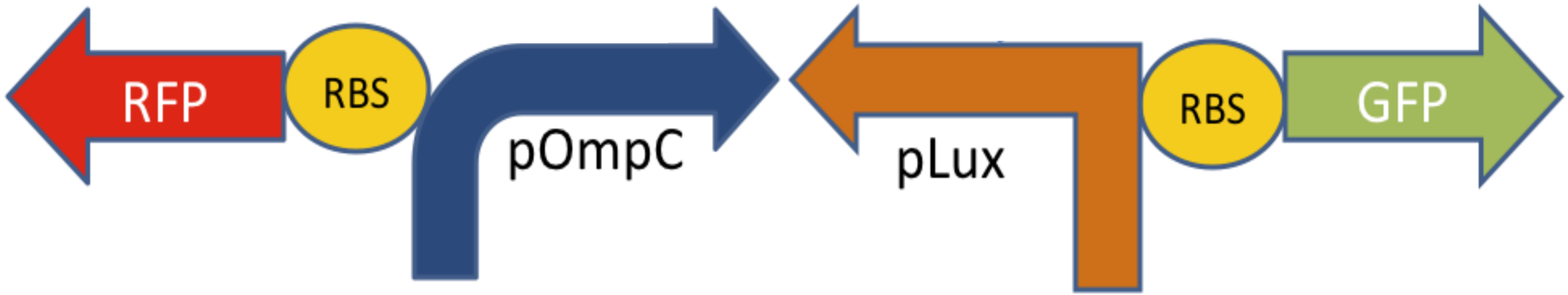
Time-Delayed Bacterial Growth



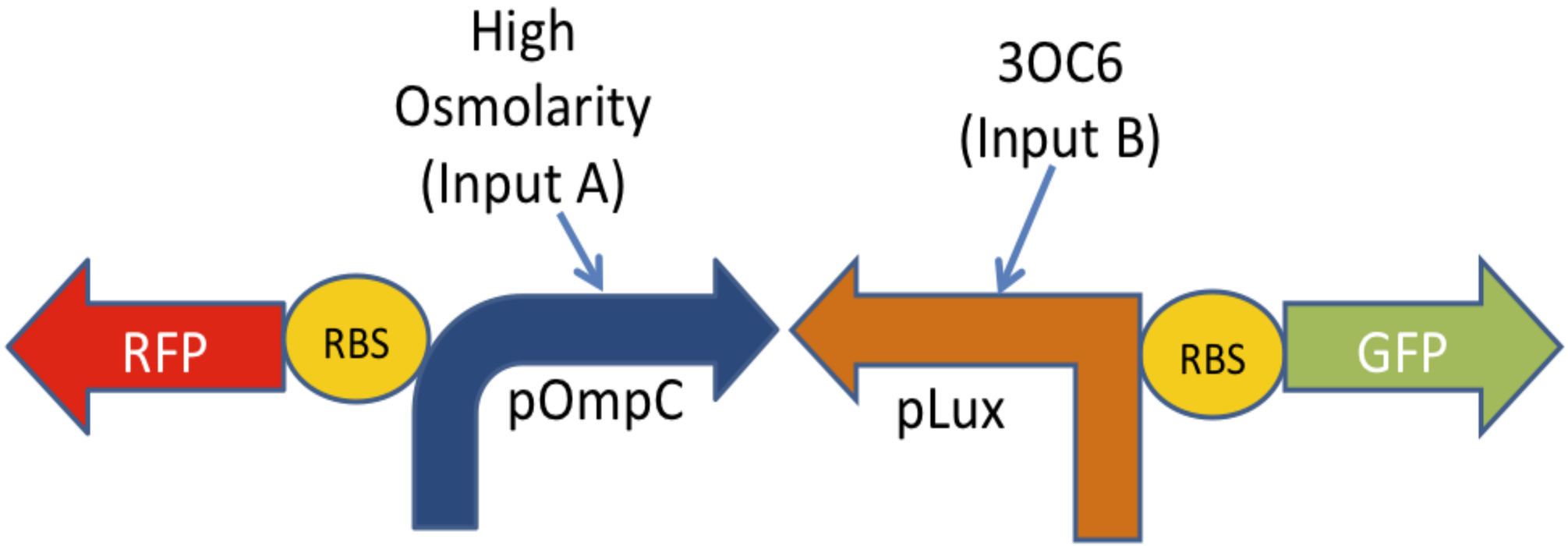
Time-Delayed Bacterial Growth



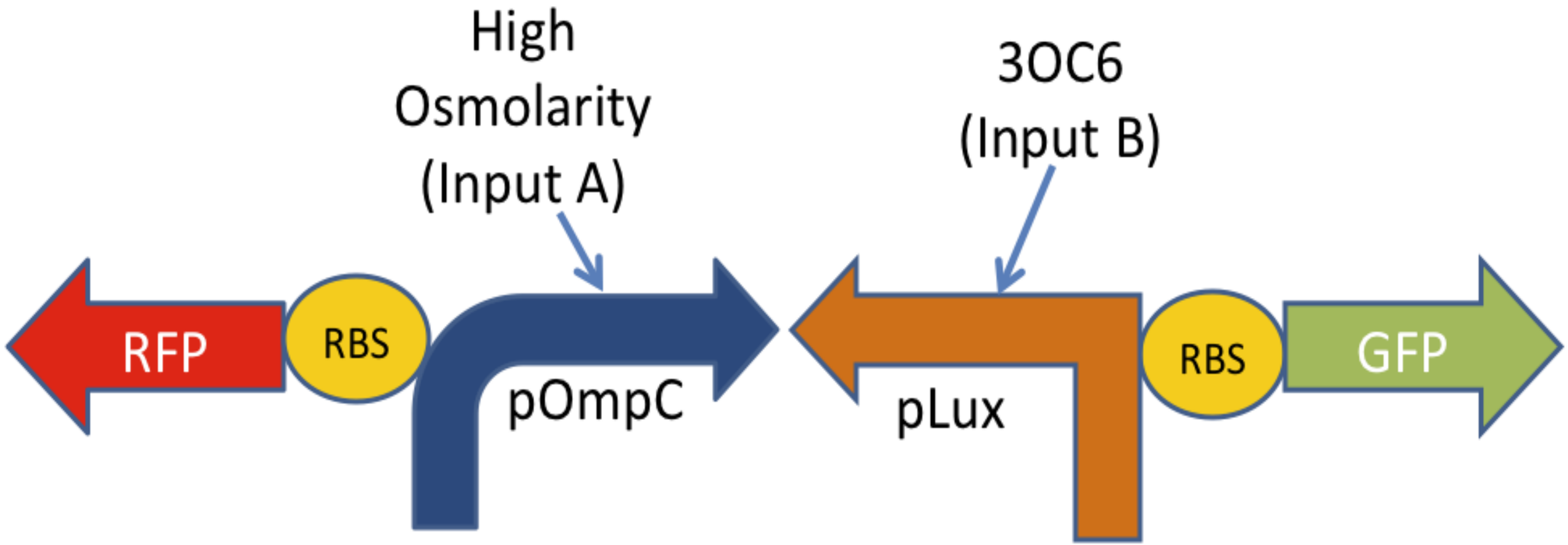
DNA-based XOR Logic Gate



DNA-based XOR Logic Gate

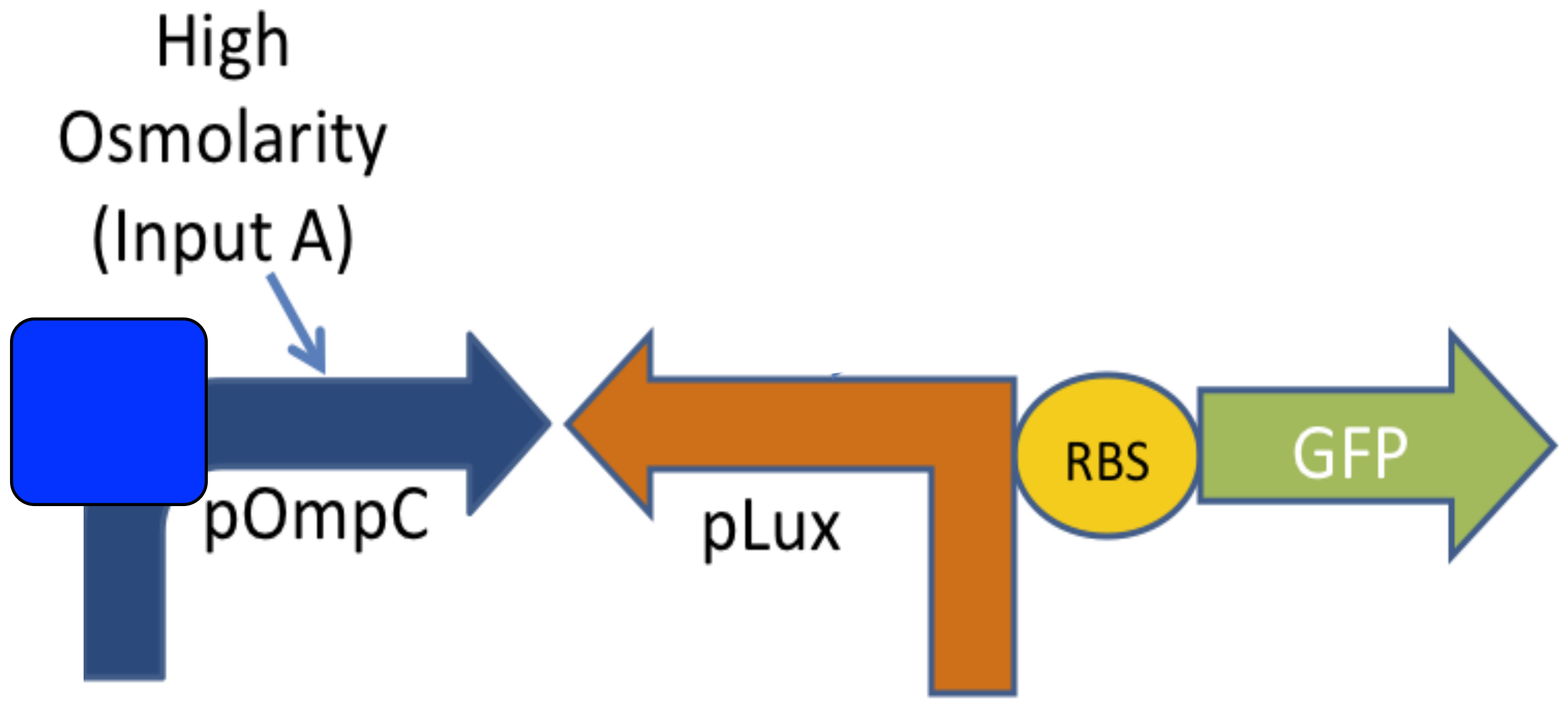


DNA-based XOR Logic Gate



High Osmolarity (Input A)	3OC6 (Input B)	Fluorescence (Output)
0	0	0
1	0	1 (GFP)
0	1	1 (RFP)
1	1	0

DNA-based XOR Logic Gate



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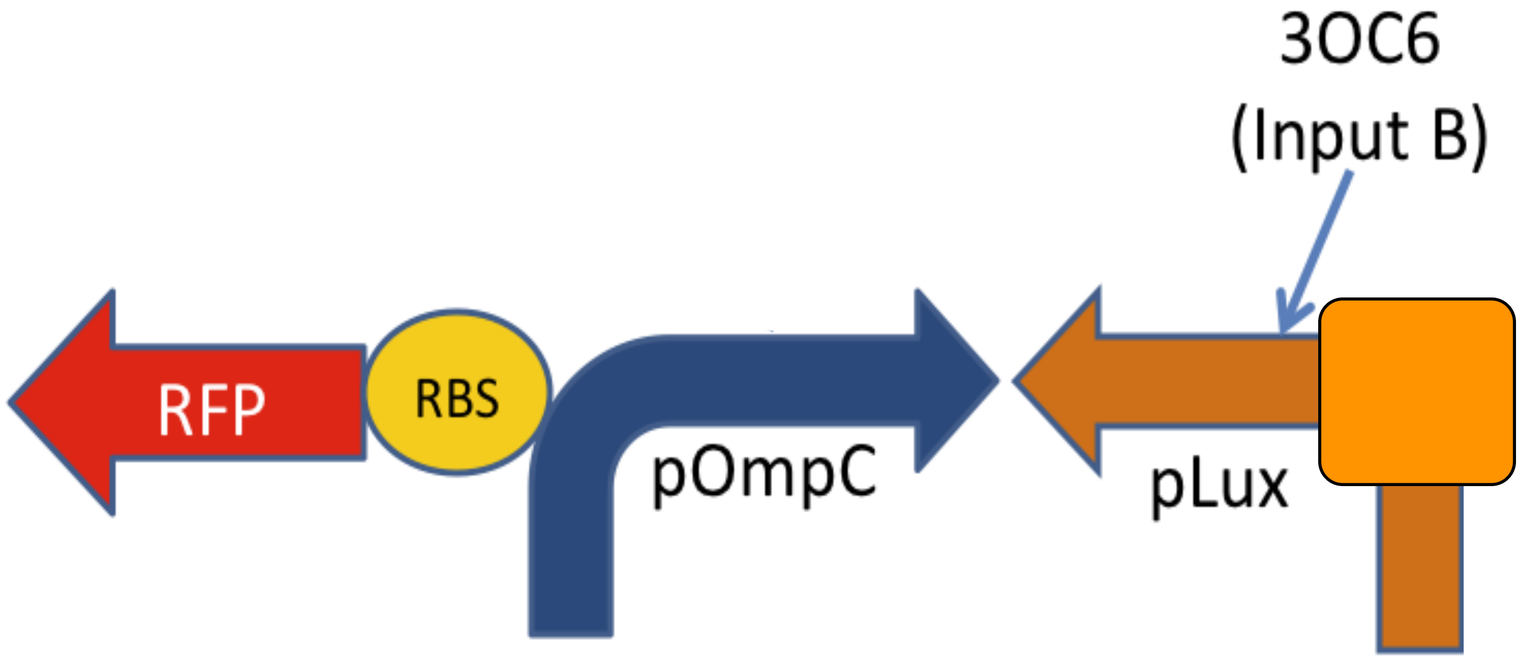

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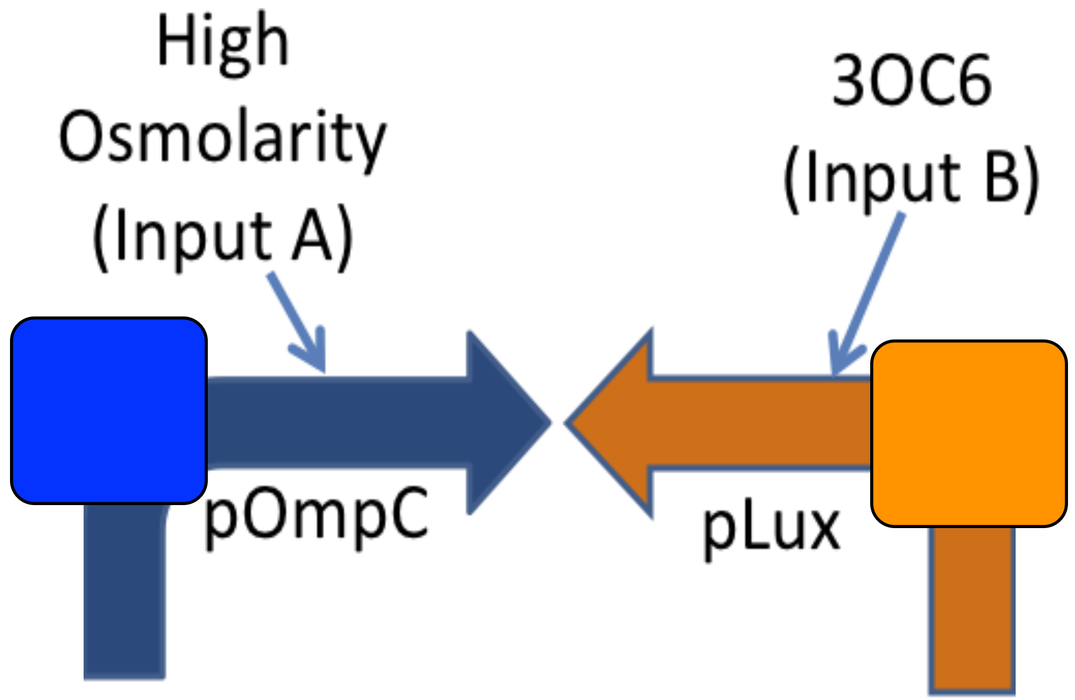

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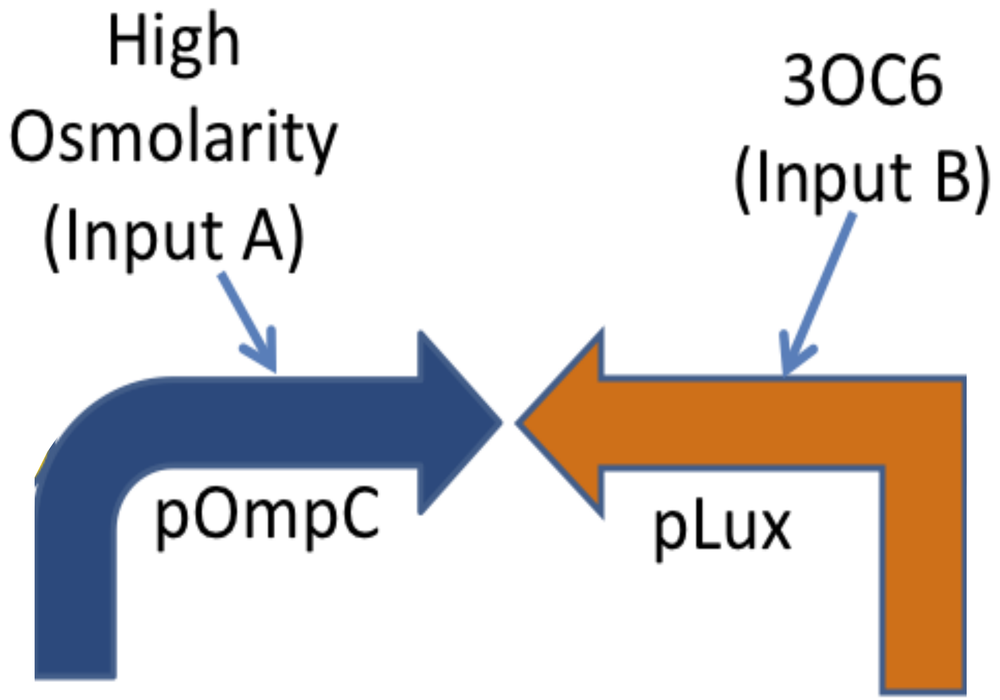
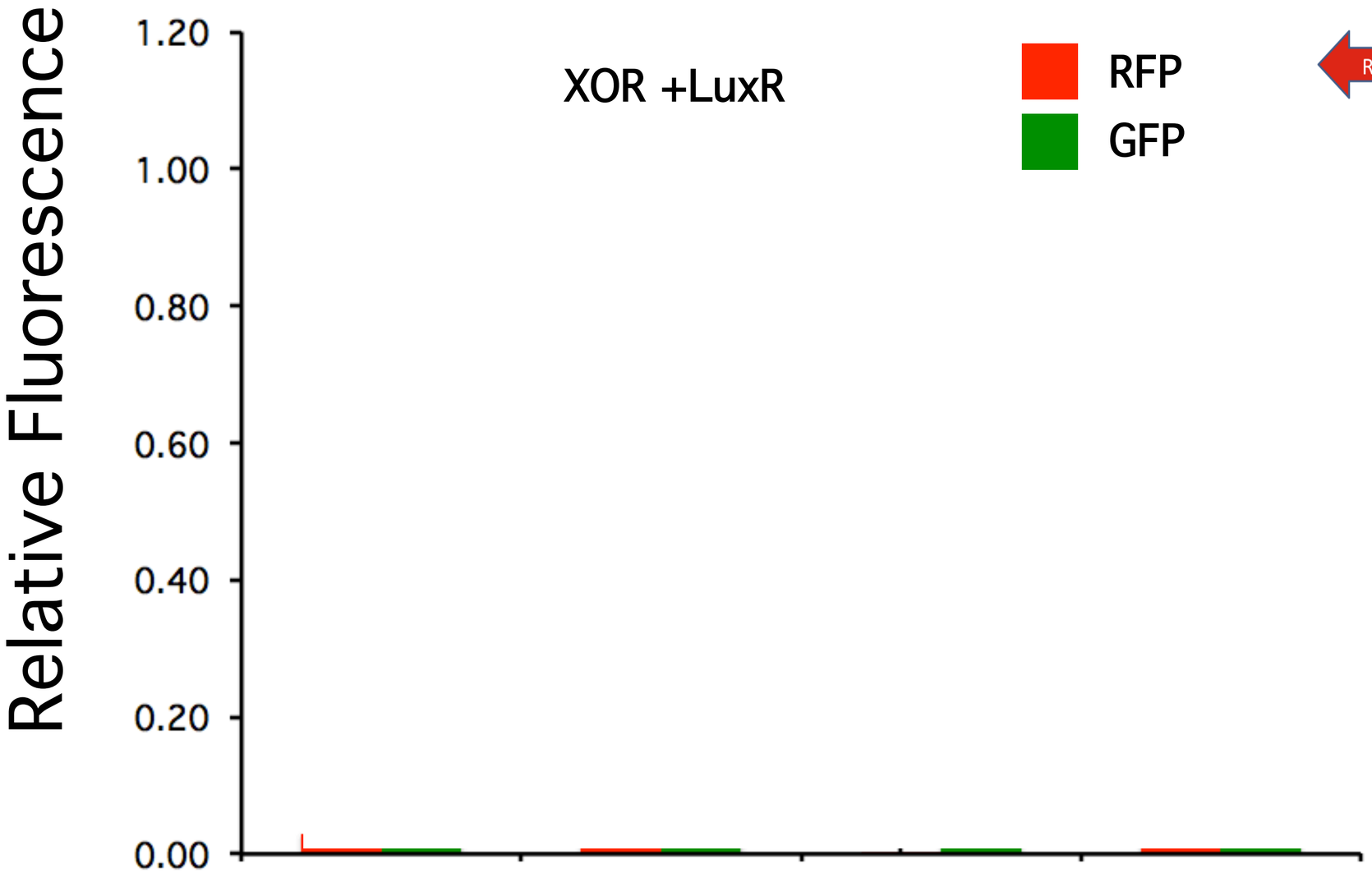


High Osmolarity (Input A)	3OC6 (Input B)	Fluorescence (Output)
0	0	0
1	0	1 (GFP)
0	1	1 (RFP)
1	1	0

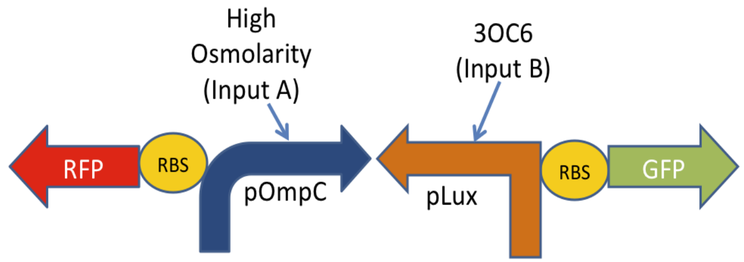
Testing Bacterial XOR Logic Gate



XOR +LuxR

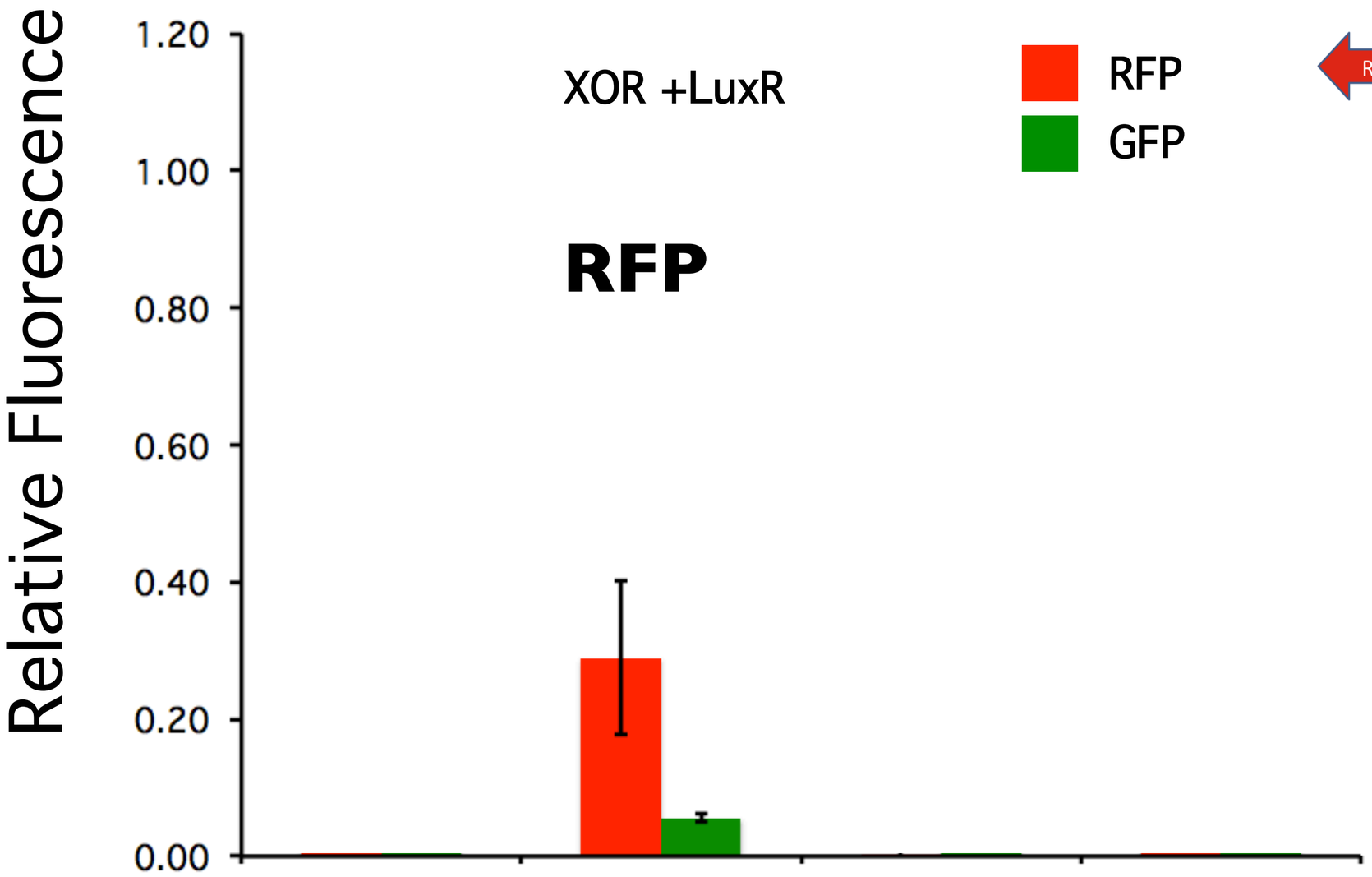
RFP

GFP



LB	-	-	+	+
3OC6	-	+	-	+

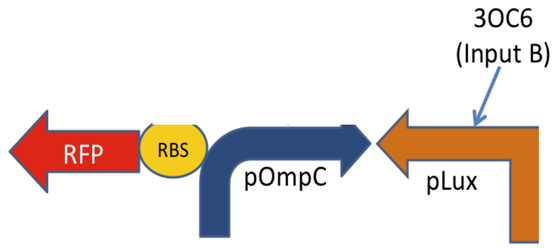
Testing Bacterial XOR Logic Gate



XOR +LuxR

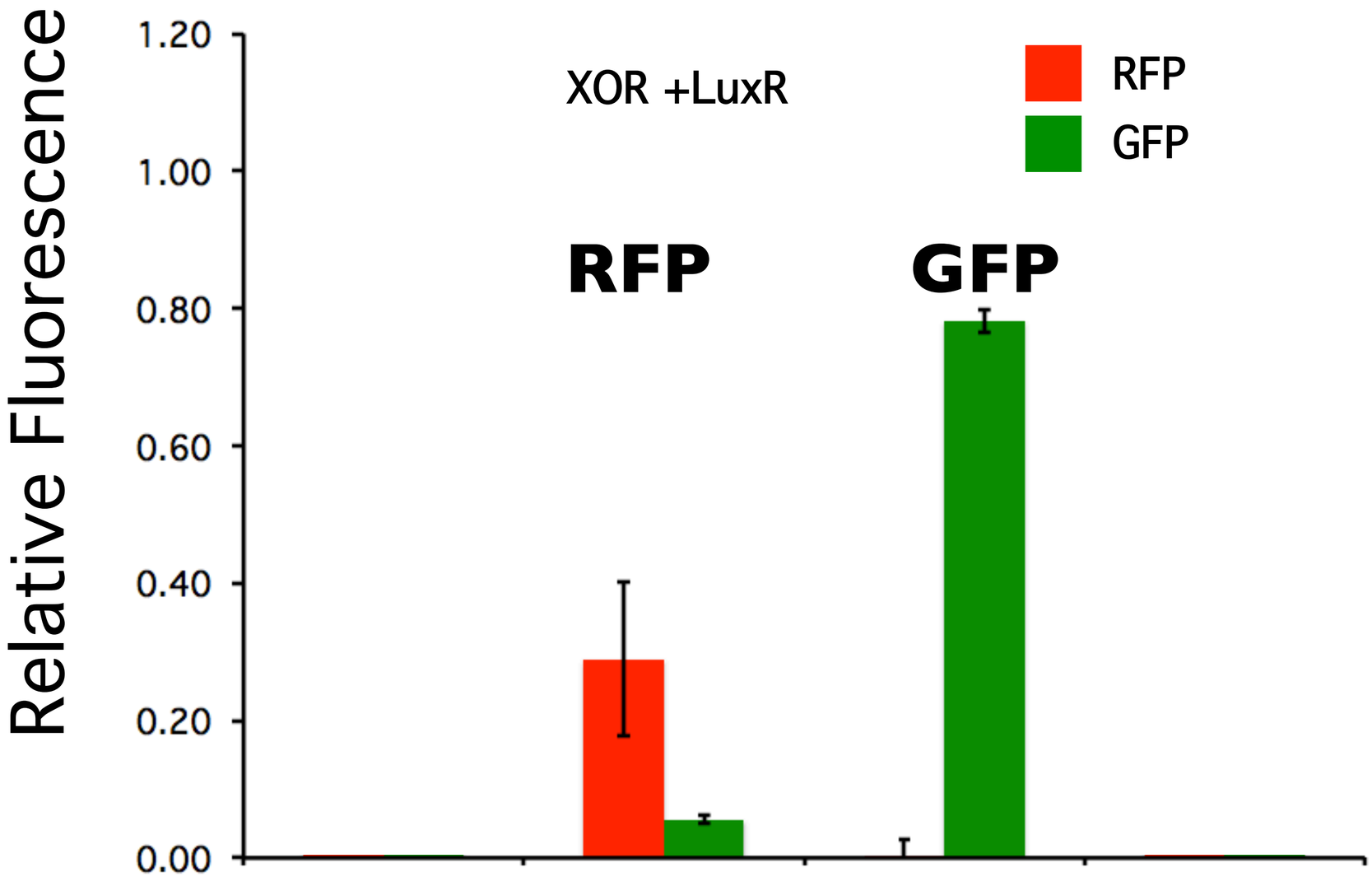
RFP

RFP
GFP

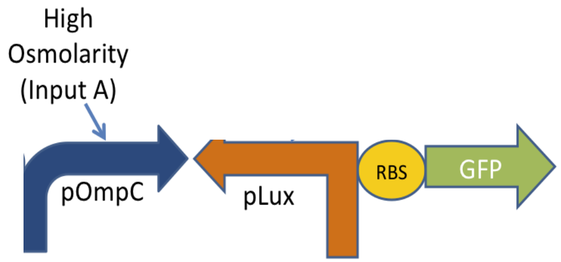


LB	-	-	+	+
3OC6	-	+	-	+

Testing Bacterial XOR Logic Gate



LB	-	-	+	+
3OC6	-	+	-	+



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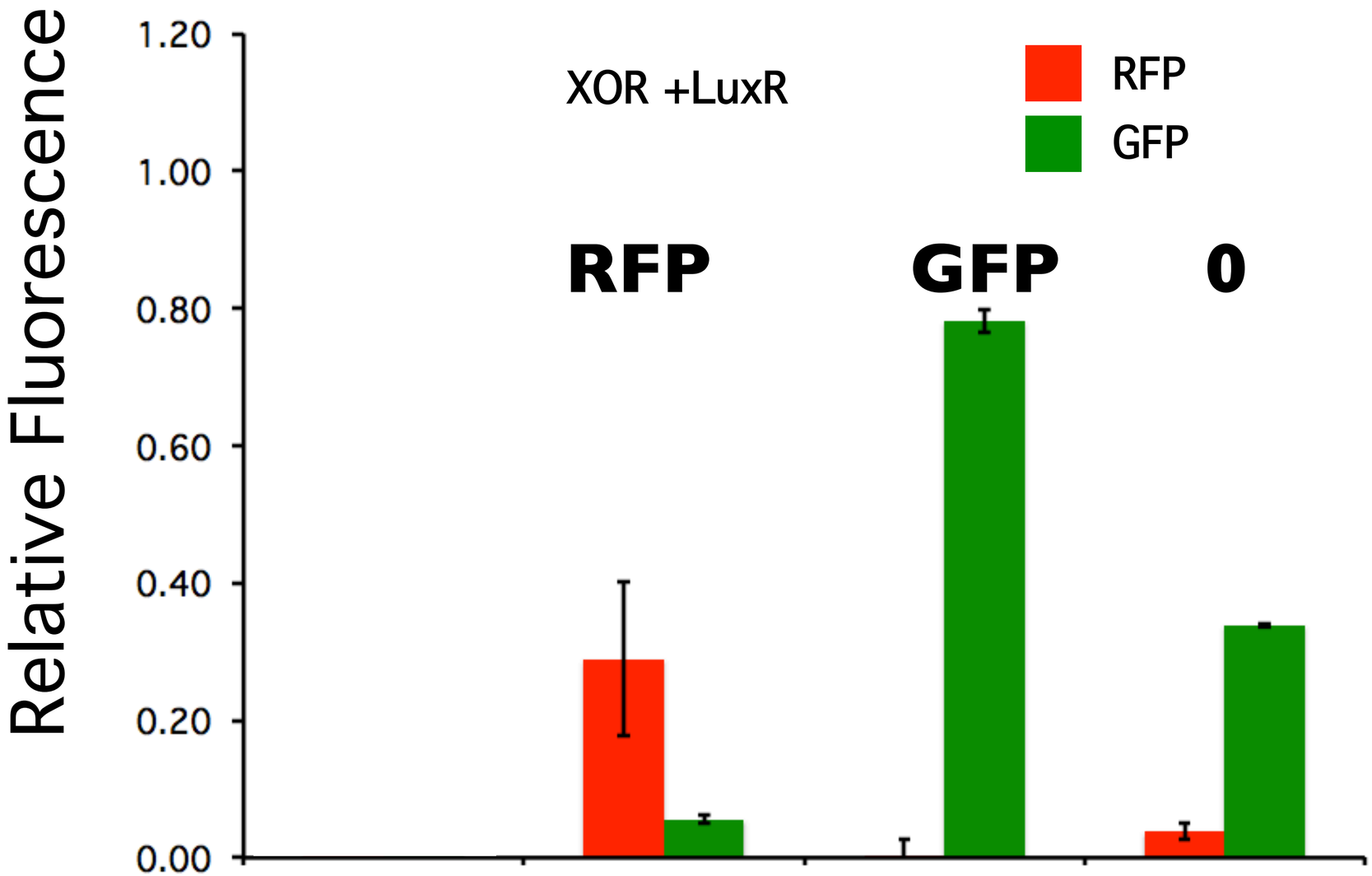
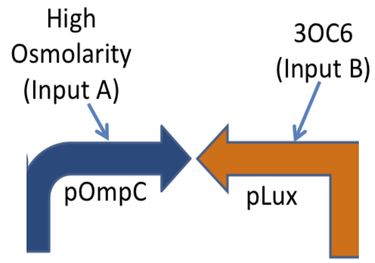
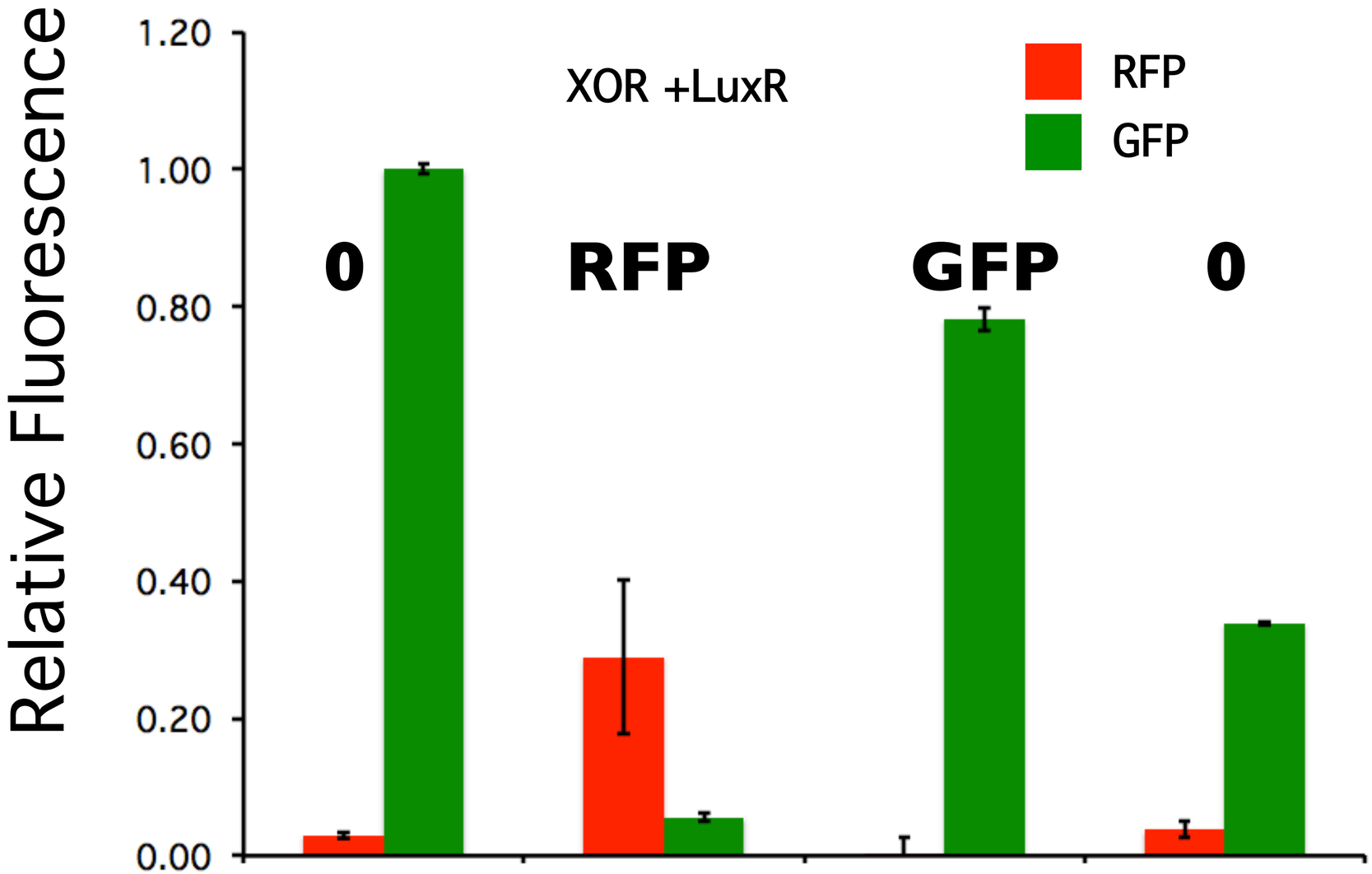
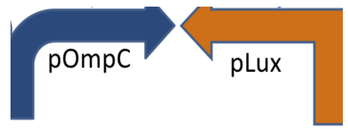




LB	-	-	+	+
3OC6	-	+	-	+

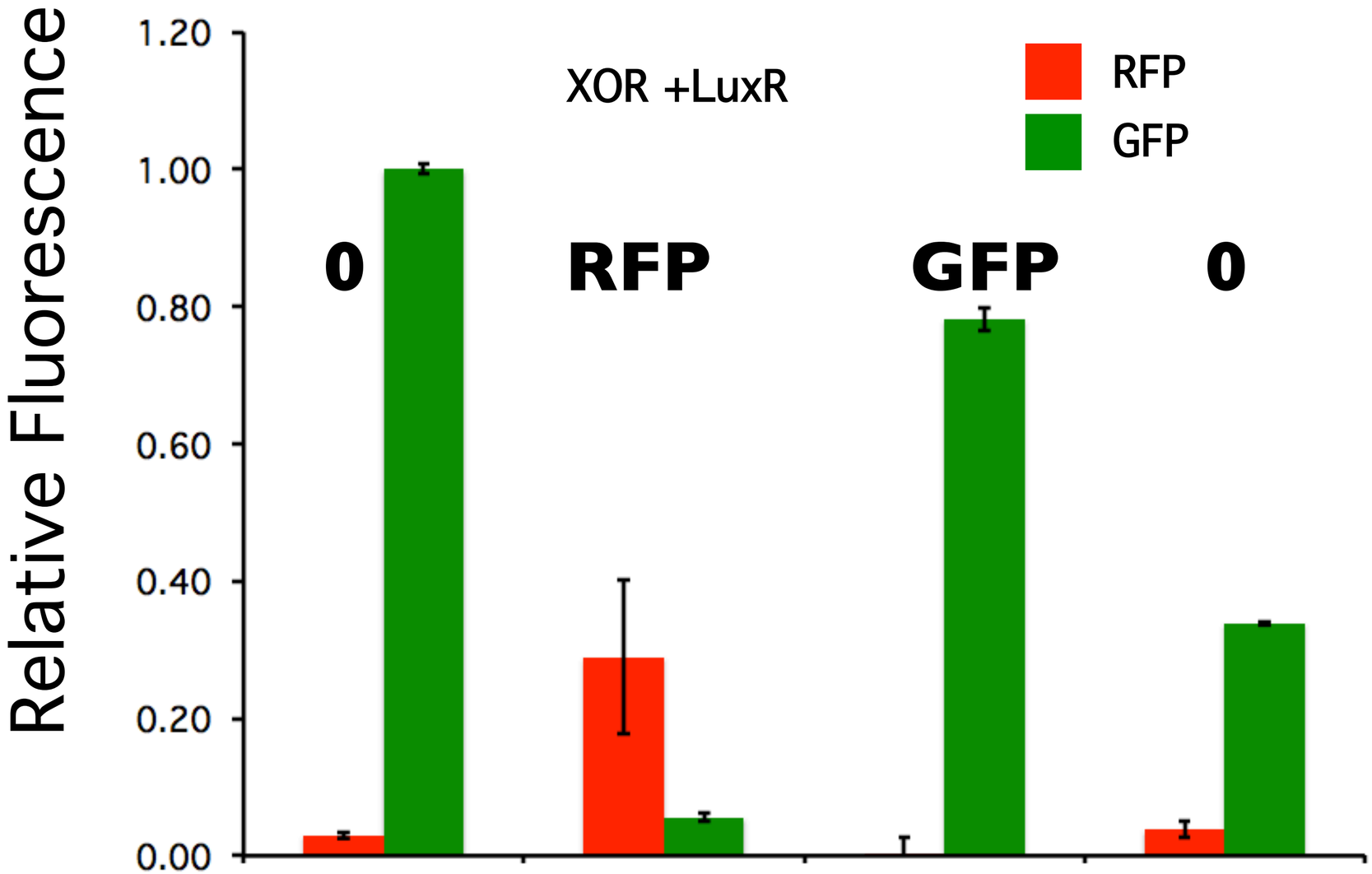
Testing Bacterial XOR Logic Gate

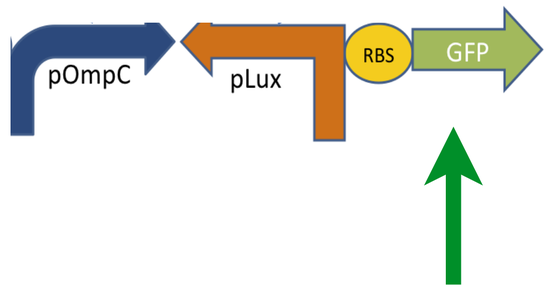




LB	-	-	+	+
3OC6	-	+	-	+

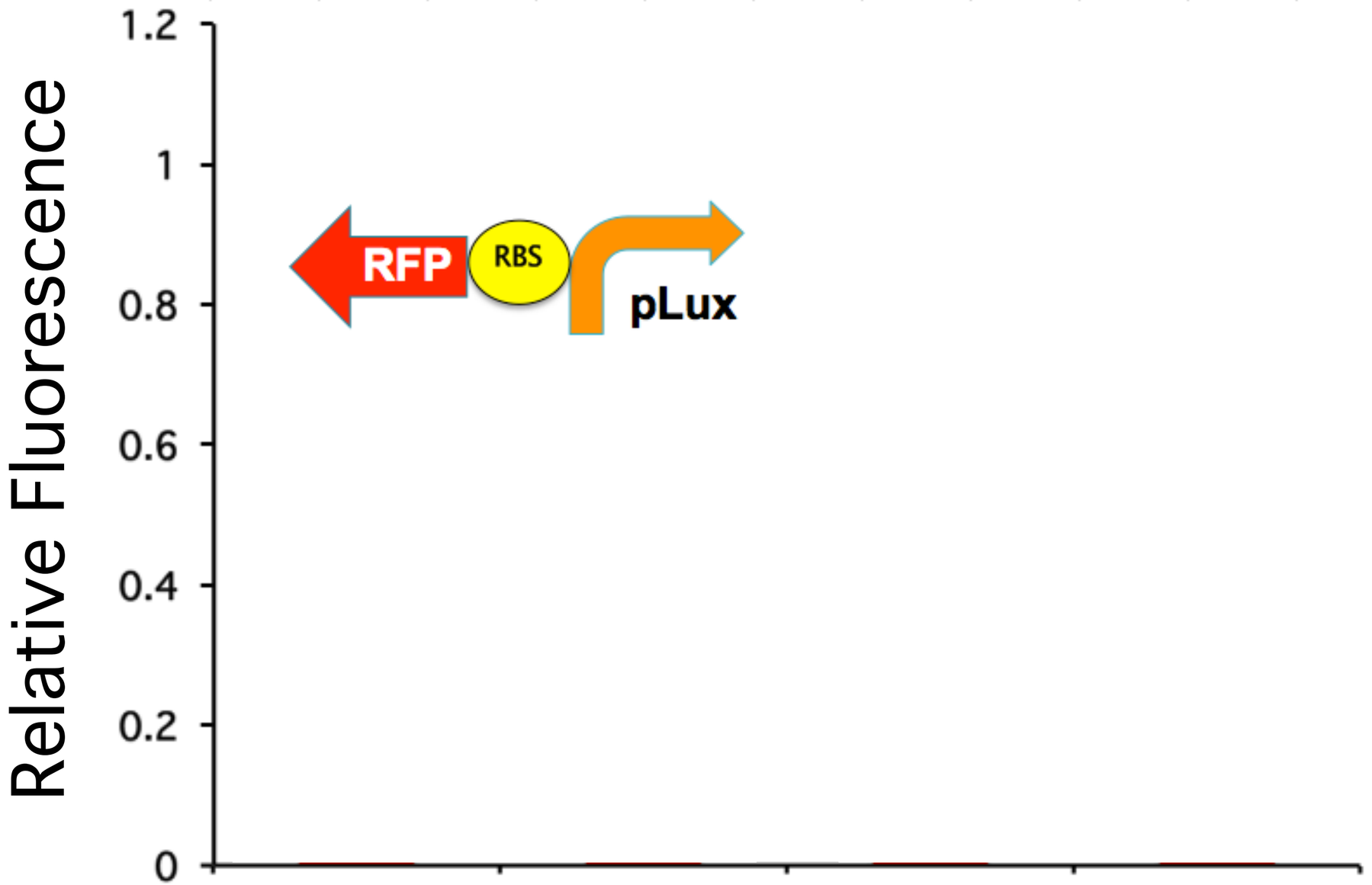
Testing Bacterial XOR Logic Gate





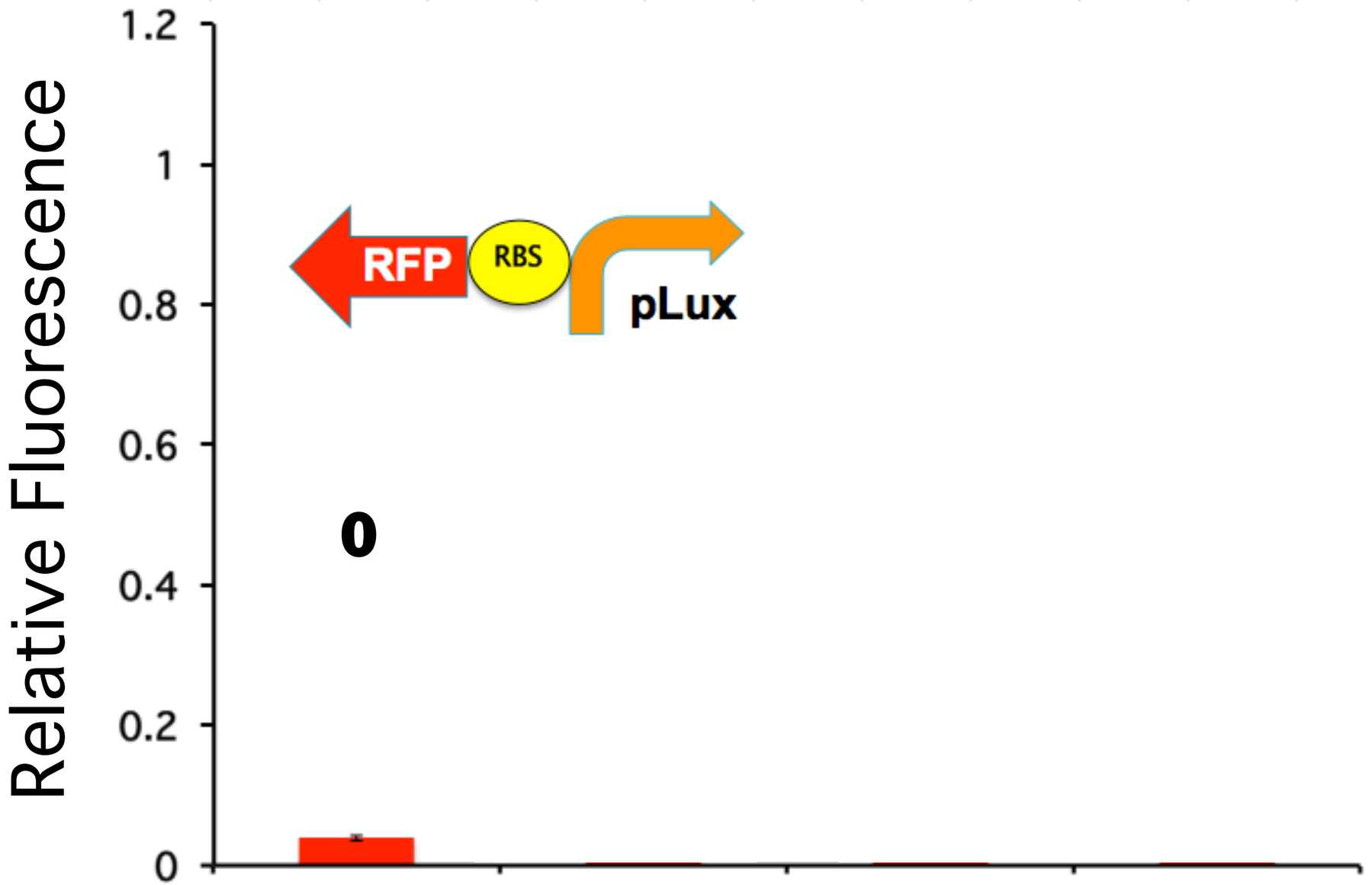
LB	-	-	+	+
3OC6	-	+	-	+

pLux + LuxR Promotes Backwards



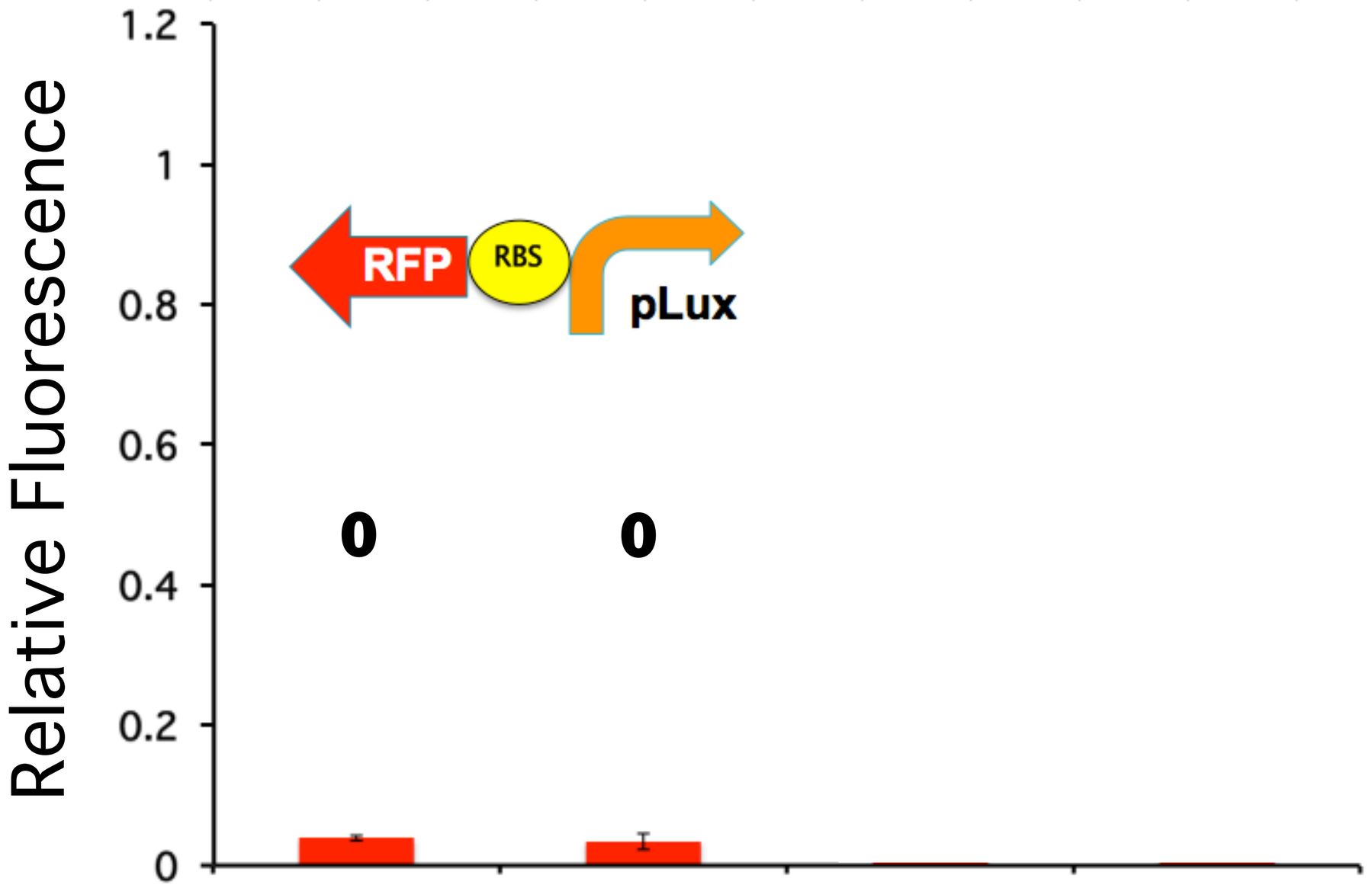
LuxR	-	-	+	+
3OC6	-	+	-	+

pLux + LuxR Promotes Backwards



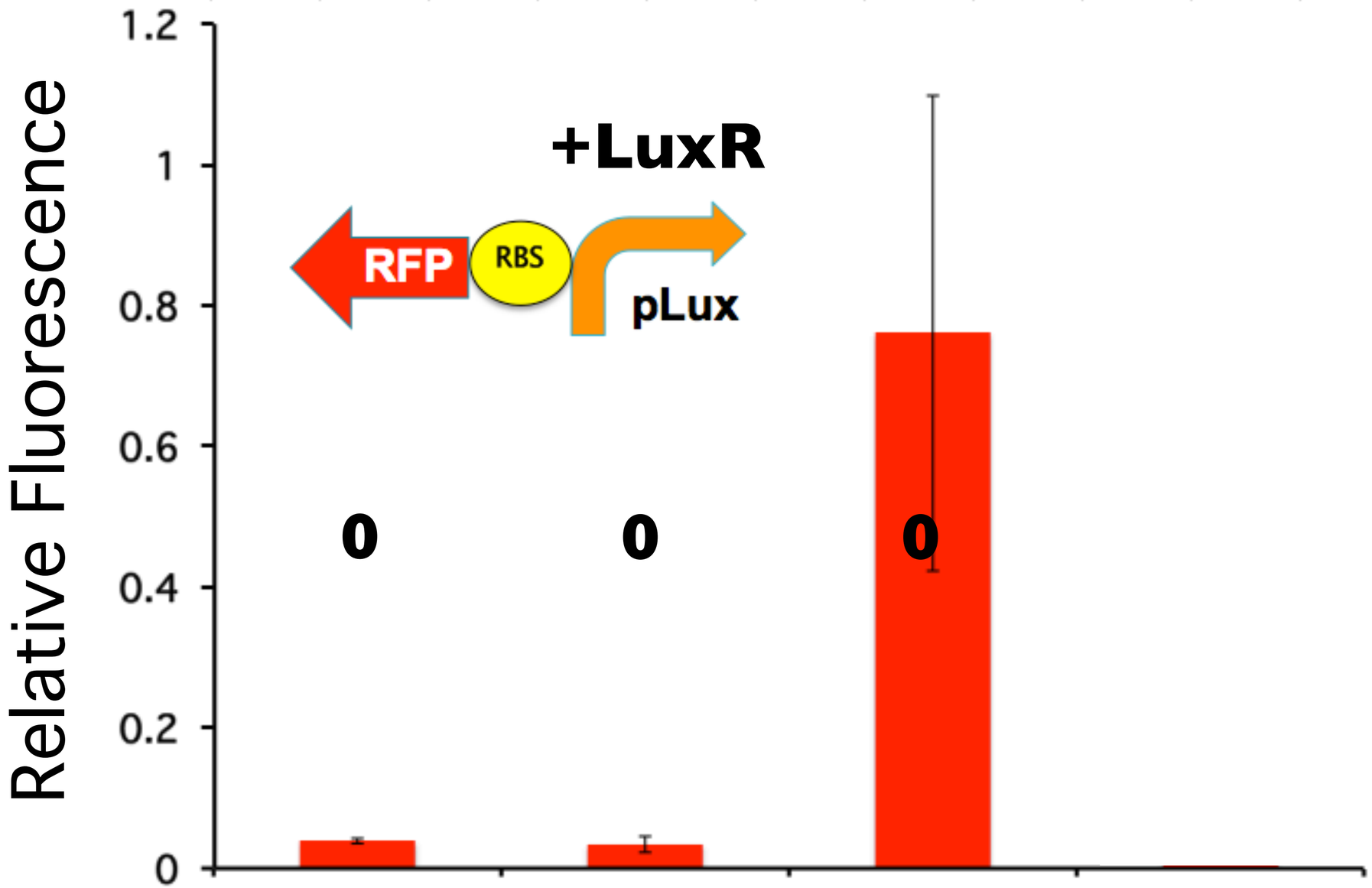
LuxR	-	-	+	+
3OC6	-	+	-	+

pLux + LuxR Promotes Backwards



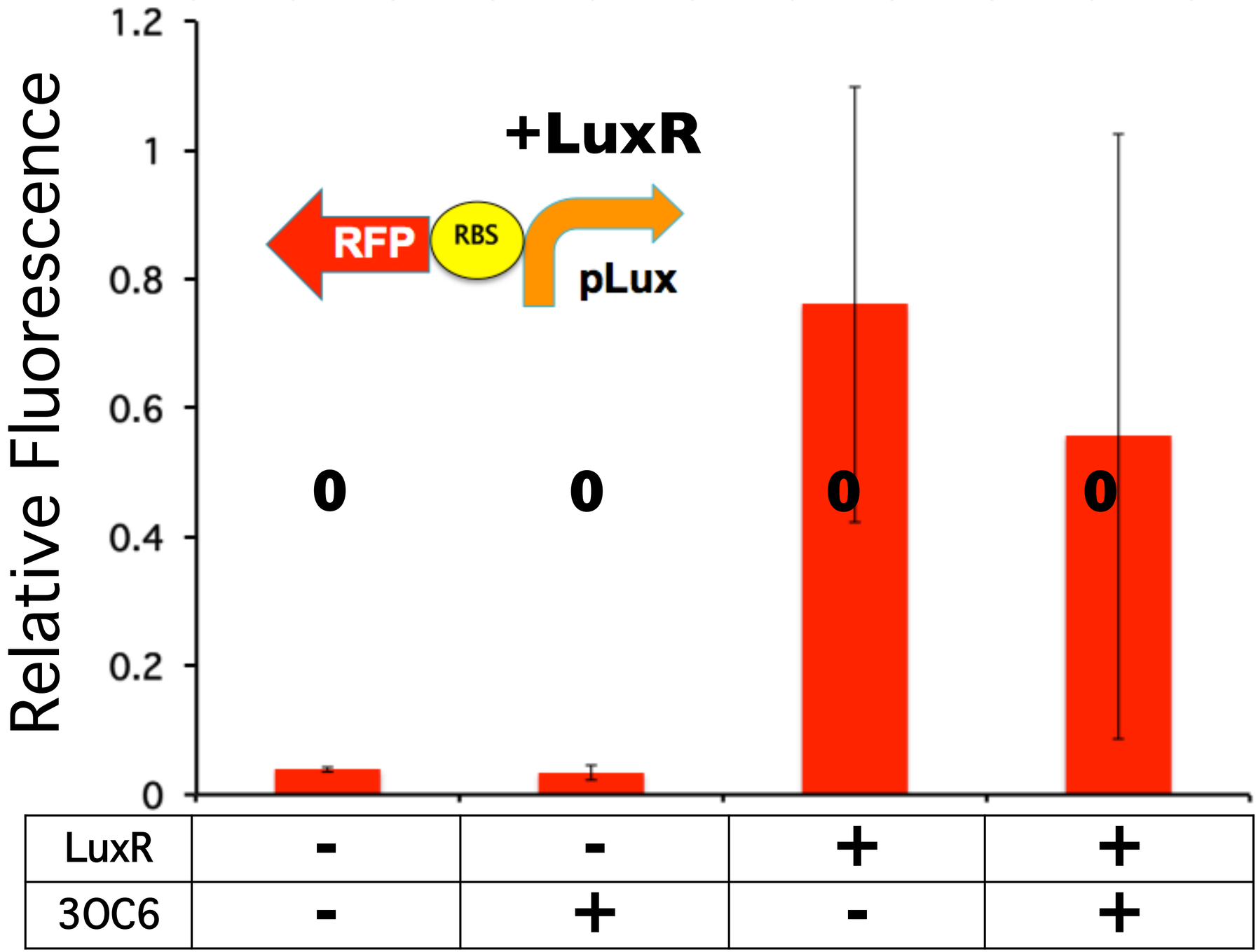
LuxR	-	-	+	+
3OC6	-	+	-	+

pLux + LuxR Promotes Backwards

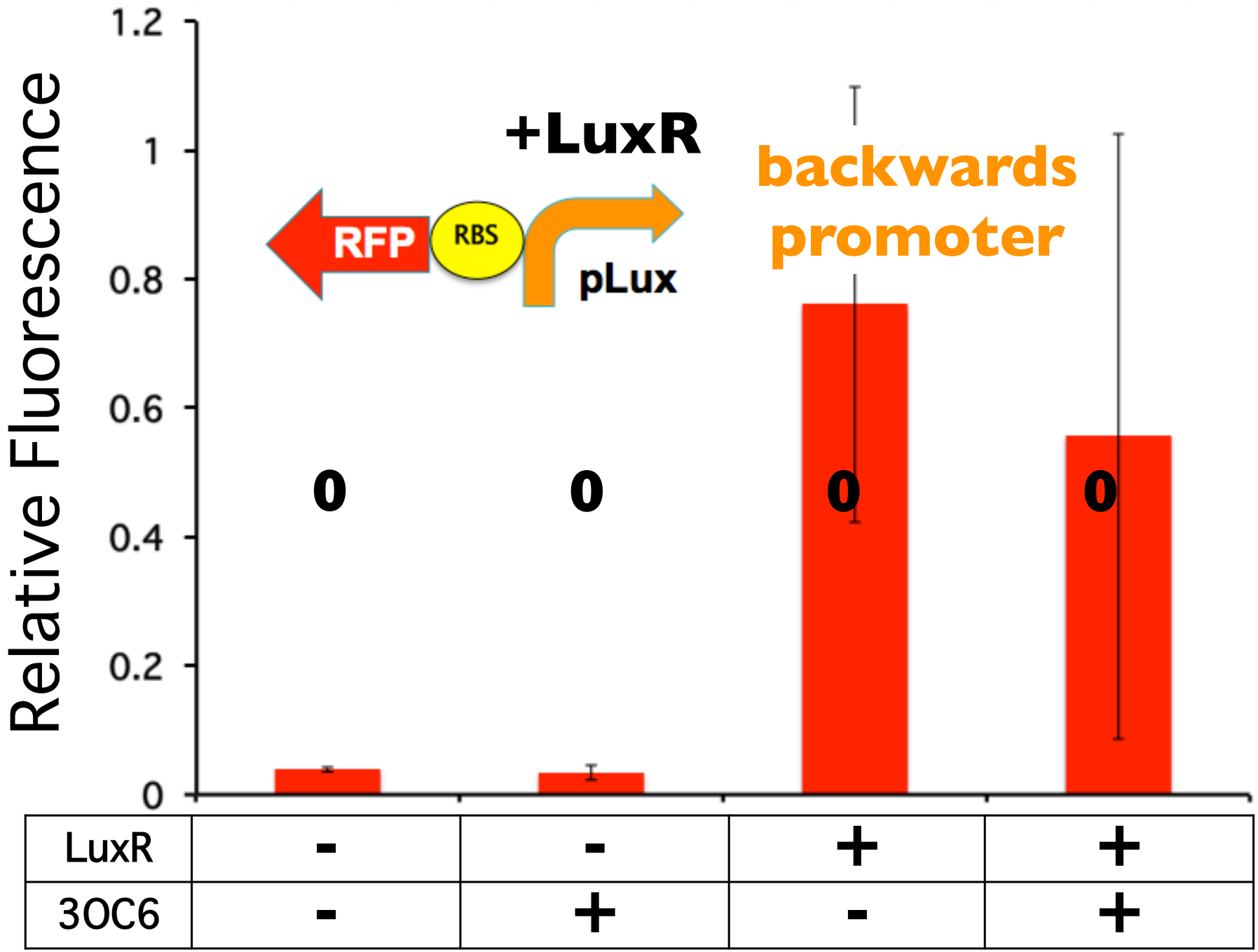


LuxR	-	-	+	+
3OC6	-	+	-	+

pLux + LuxR Promotes Backwards

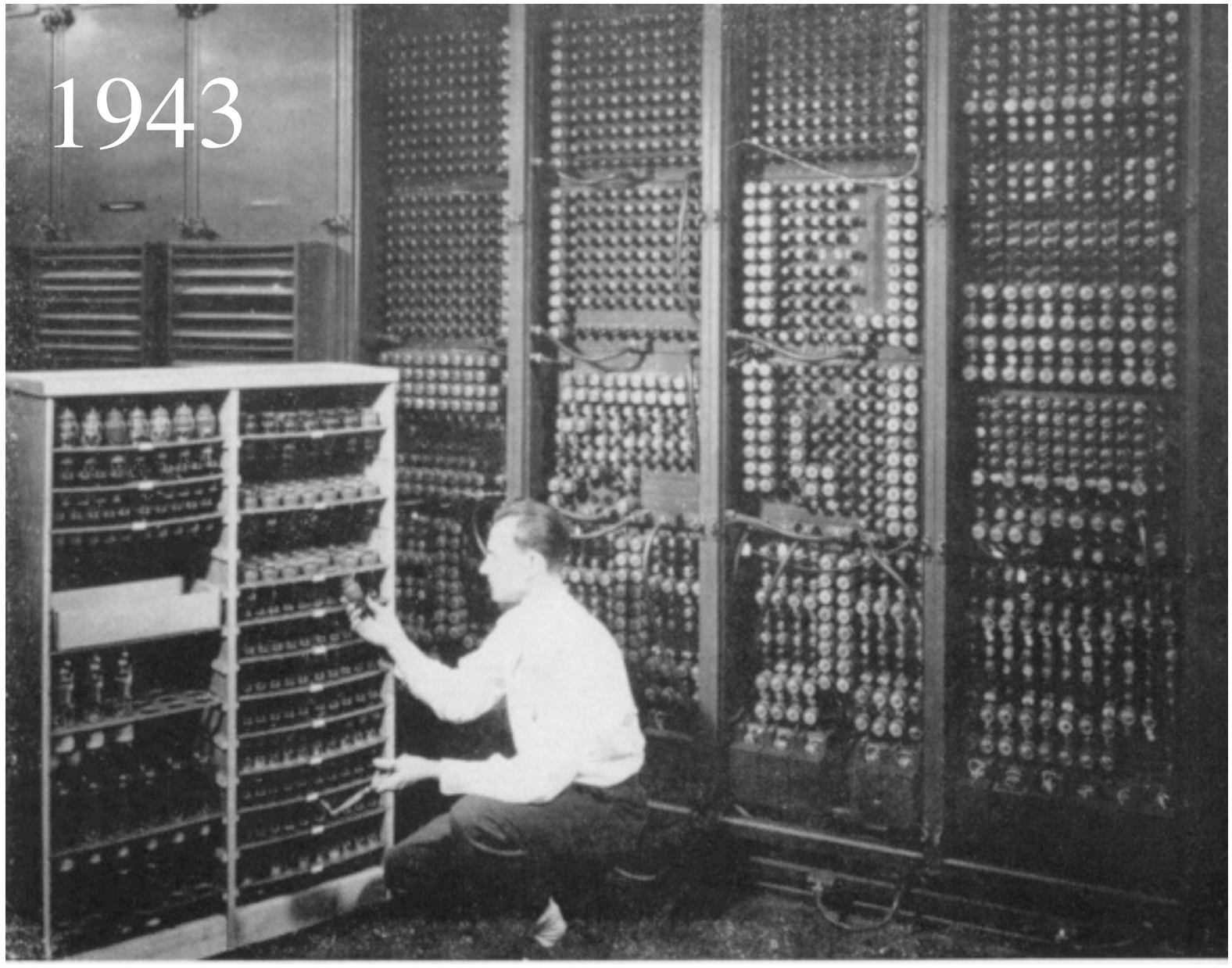


pLux + LuxR Promotes Backwards



Why build bacterial computers?

Evolution of Computers

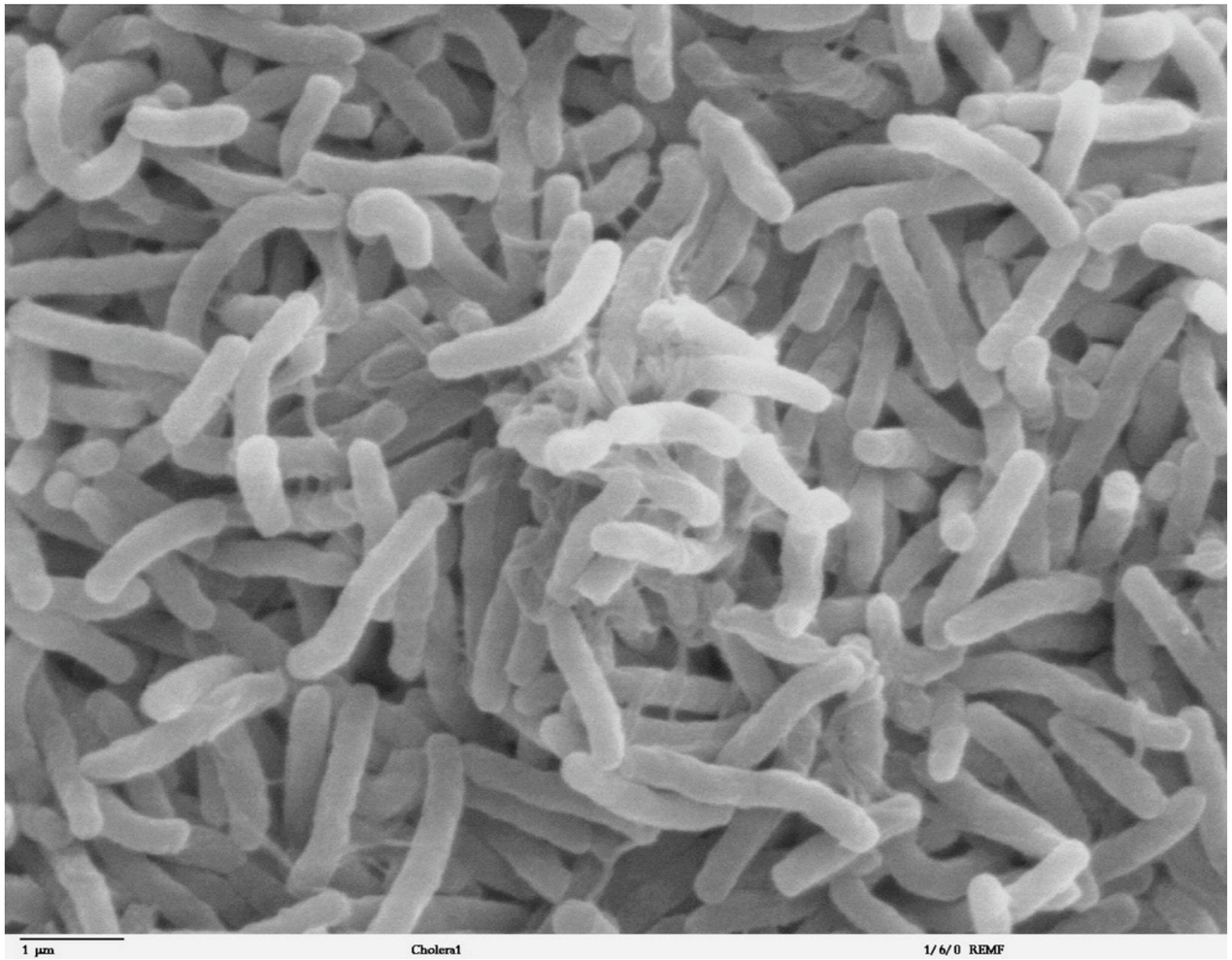


Evolution of Computers

iPhone in 2012

Evolution of Bacterial Computers

E. coli in 2012



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Living Hardware in 2022

Collaborative 2012 Research Team

DAVIDSON

Discover Gold WESTERN

Saturday, July 28, 2012

Davidson 2012 Research Team

The scenery only changes for the lead dog.

The scenery only changes for the lead dog.

Acknowledgements

Faculty: Laurie Heyer, Jeff Poet, Todd Eckdahl, Karmella Haynes, Pat Sellers, Mark Barsoum

Students: Romina Clemente, Clif Davis, A.J. Grant, Mary Gearing, Kin Lau, Olivia Ho-Shing, Shamita Punjabi, Eric Sawyer, Ashley Schooner, Siya Sun, Shashank Suresh, Bryce Szczepanik, Leland Taylor, Annie Temmink, Alyndria Thompson, Will Vernon, Oyinade Adefuye, Will DeLoache, Jim Dickson, Andrew Martens, Amber Shoecraft, Mike Waters, Jordan Baumgardner, Tom Crowley, Lane Heard, Nick Morton, Michelle Ritter, Karen Acker, Bruce Henschen, Jessica Treece, Matt Unzicker, Amanda Valencia, Lance Harden, Sabriya Rosemond, Samantha Simpson, Erin Zwack, Marian Broderick, Adam Brown, Trevor Butner, Lane Heard, Eric Jessen, Kelley Malloy, Brad Ogden, Kelly Davis, Alicia Allen, James Barron, Robert Cool, Kelly Davis, Will DeLoache, Erin Feeney, Andrew Gordon, John Igo, Aaron Lewis, Kristi Muscalino, Madeline Parra, Pallavi Penumetcha, Karlesha Roland, Max Win, Xiao Zhu, Kristen DeCelle, Matt Gemberling, Oscar Hernandez, Andrew Drysdale, Nick Cain, Tamar Odel, and Jackie Ryan.

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

Saturday, July 28, 2012

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?’ ”

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