Improving Biology Learning Outcomes in Courses and Research

A. Malcolm Campbell
Davidson College

April 21, 2016

DAVIDSON

Outline for Talk

Synthetic Biology Research Topics

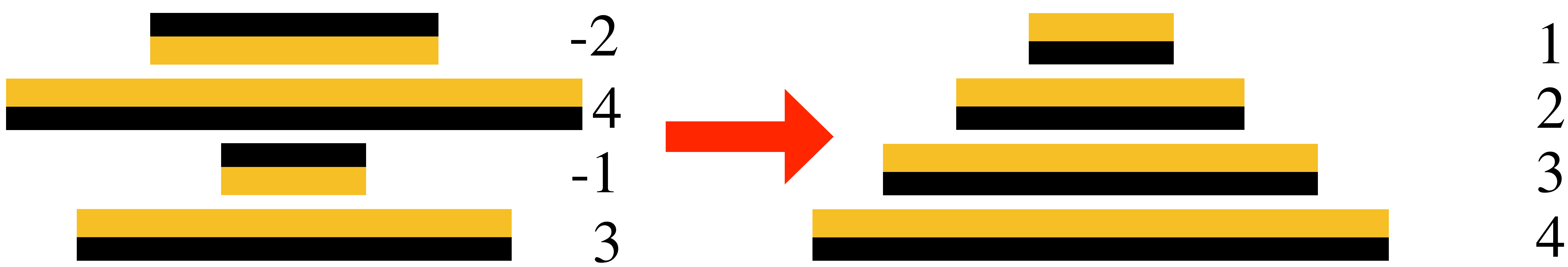
Introductory Biology SynBio Lab Research

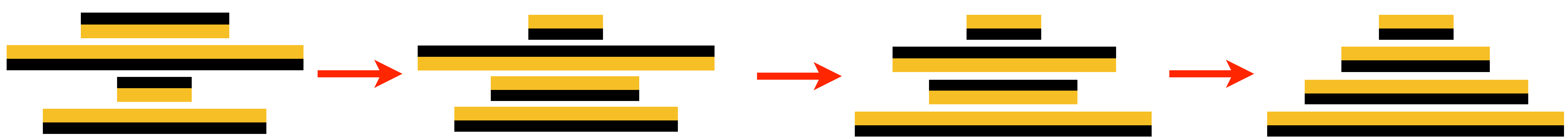
Introductory Biology Overhaul

Learning Outcomes

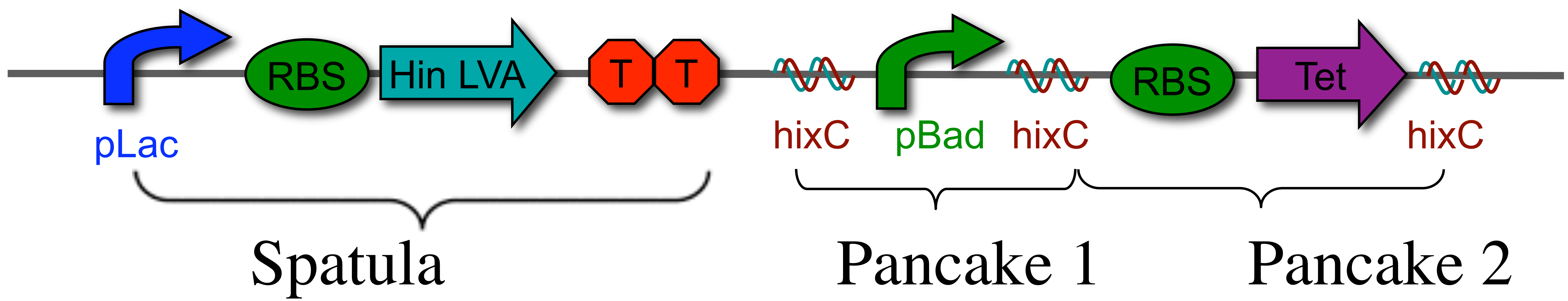
Basic Research with Undergraduates: making bacterial computers

Burnt Pancake Problem





DNA Burnt Pancakes



abstractions of DNA parts

Outstanding Publication of 2008
in the
Journal of Biological Engineering

On behalf of the editors of *Journal of Biological Engineering*, we recognize the contribution of the follow authors for the most outstanding publication of the year.

"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)

JOURNAL OF BIOLOGICAL ENGINEERING

Mark R. Riley, 2006-2008 Editor-in-chief

Institute of Biological Engineering


2. Accesses 21801

Research Open Access Highly accessed

Engineering bacteria to solve the Burnt Pancake Problem

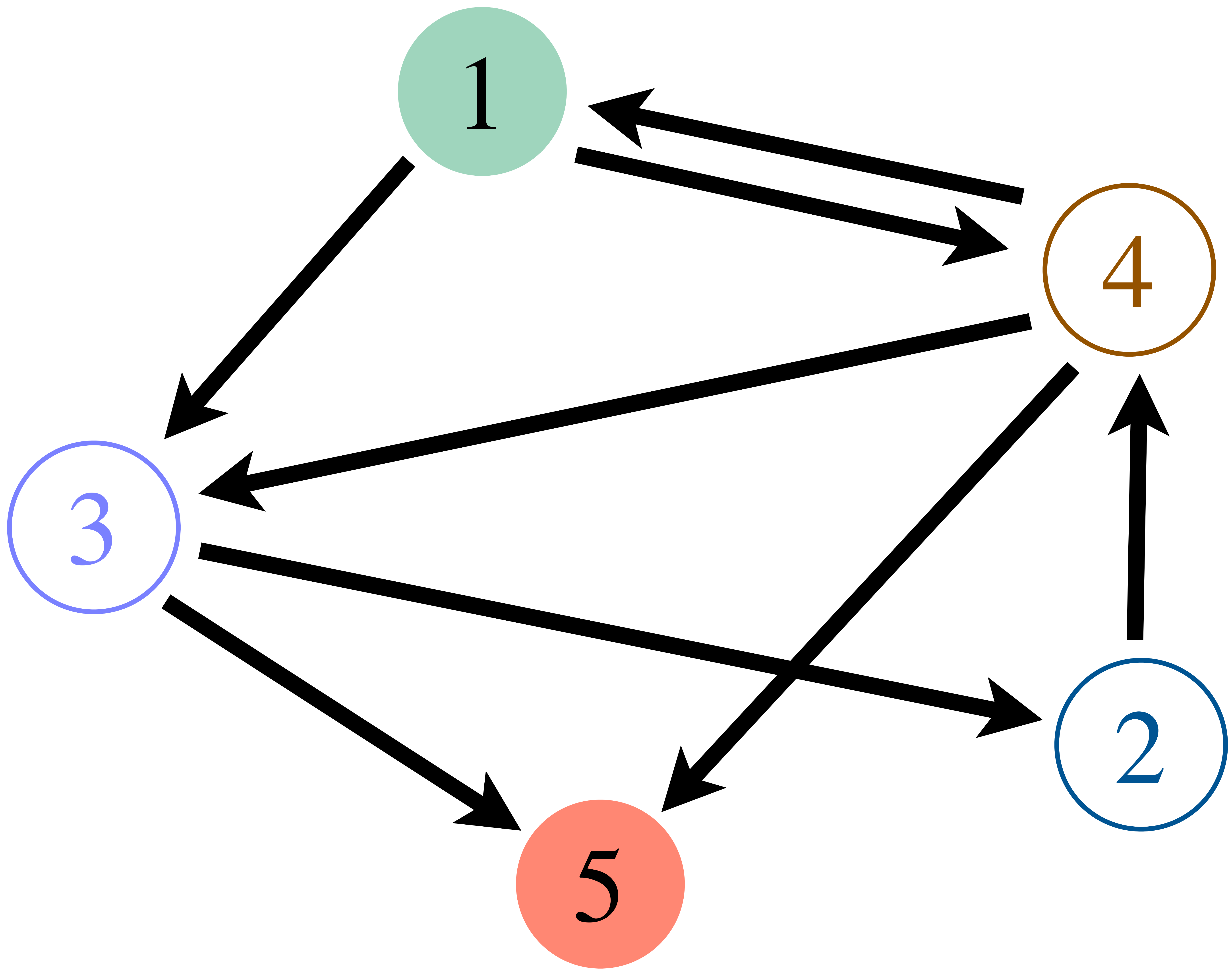
Karmella A Haynes, Marian L Broderick, Adam D Brown, Trevor L Butner, James O Dickson, W Lance Harden, Lane H Heard, Eric L Jessen, Kelly J Malloy, Brad J Ogden, Sabriya Rosemond, Samantha Simpson, Erin Zwack, A Malcolm Campbell, Todd T Eckdahl, Laurie J Heyer, Jeffrey L Poet

Journal of Biological Engineering 2008, **2**:8 (20 May 2008)

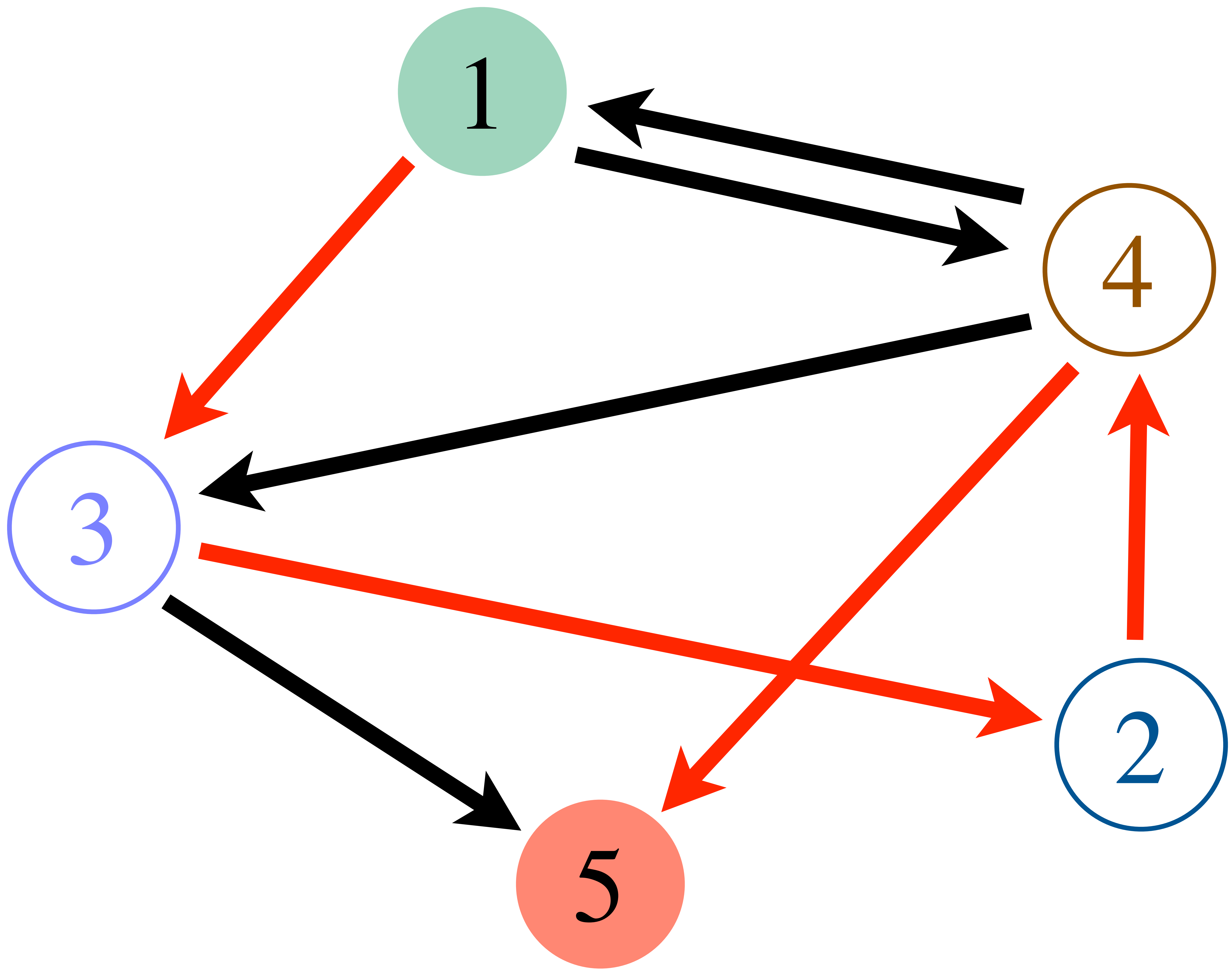
[Abstract] [Full Text] [PDF] [PubMed] [Related articles]

12 undergraduate coauthors

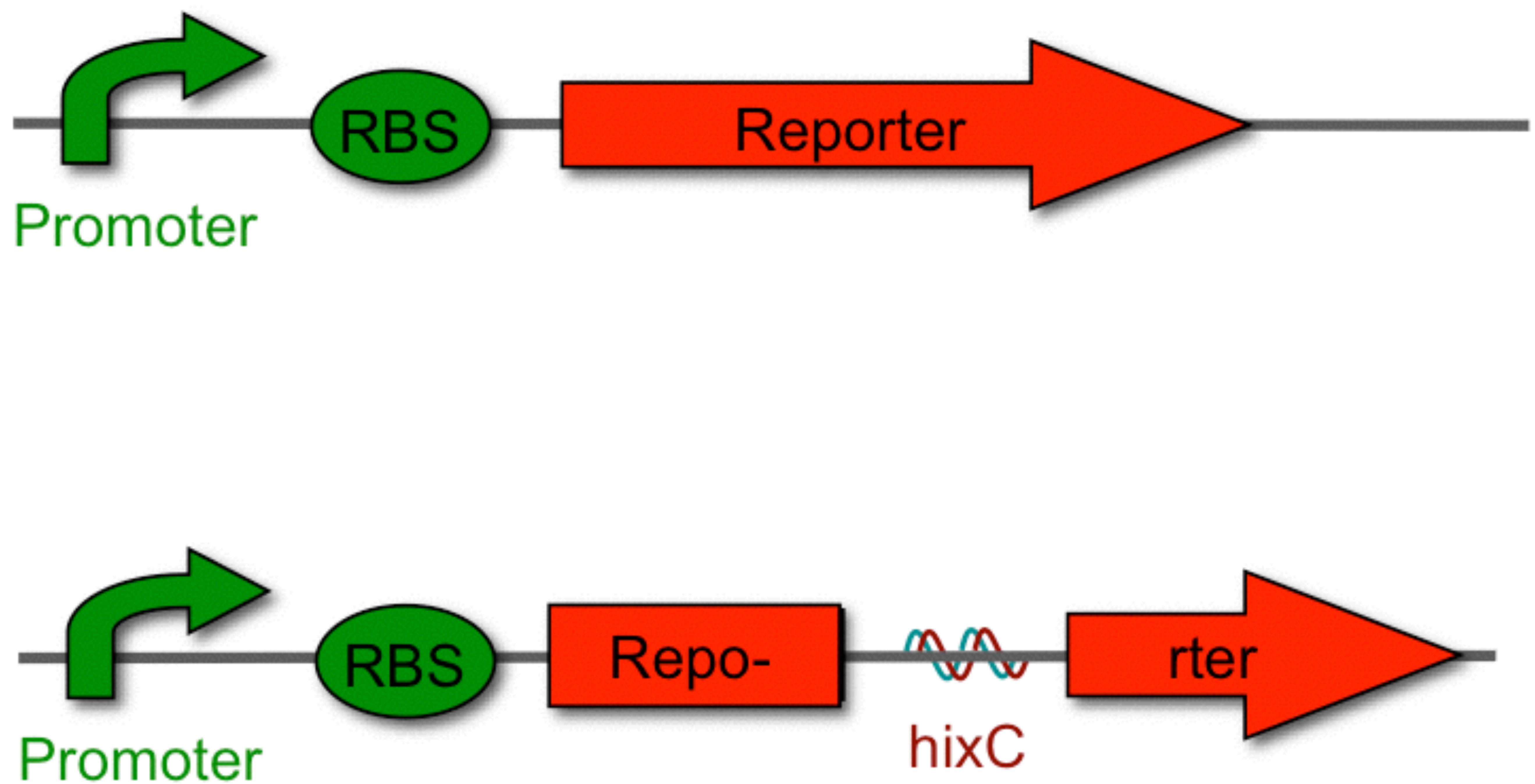
Hamiltonian Path Problem



Hamiltonian Path **Solution**

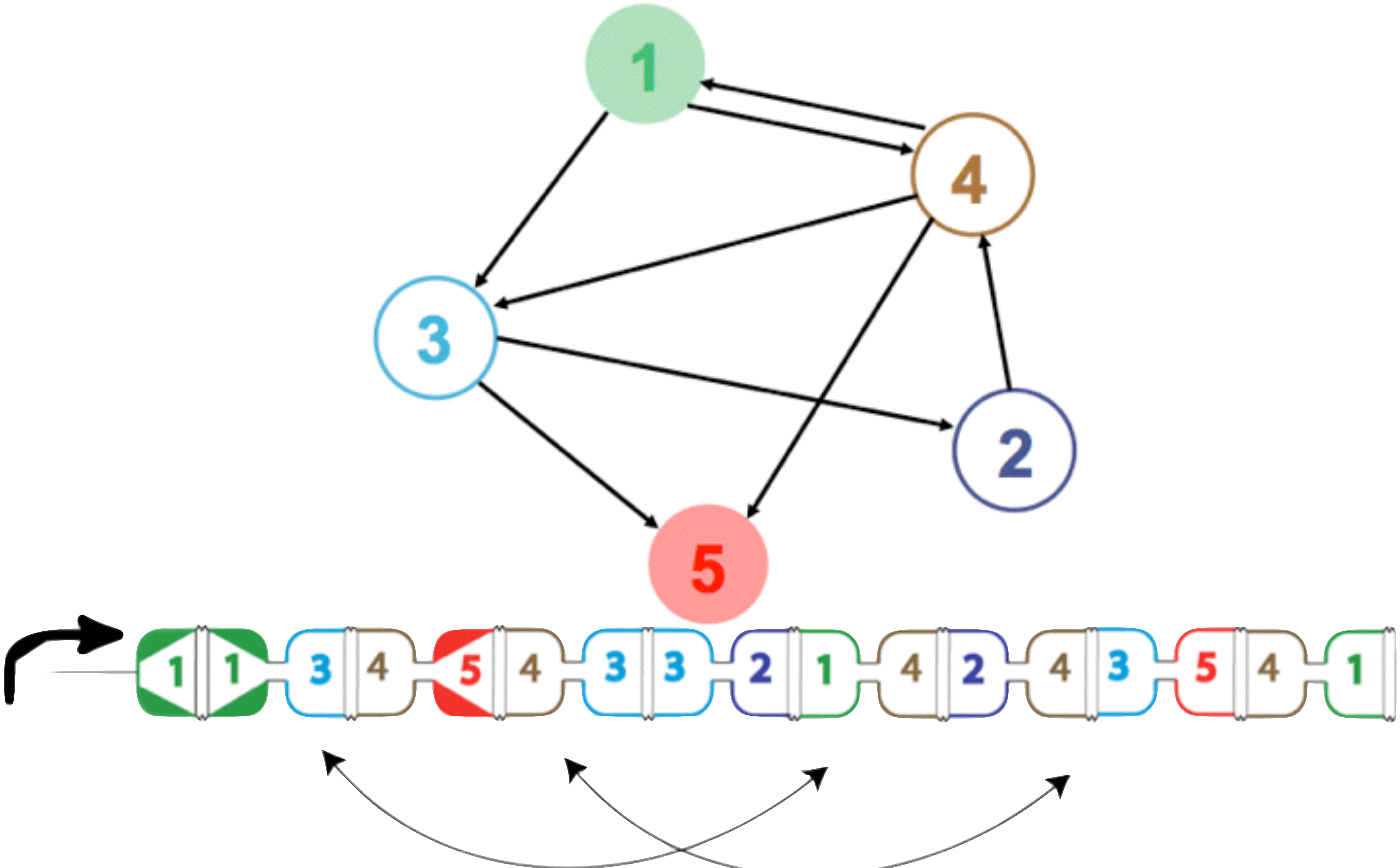


Split Genes to Encode Problem



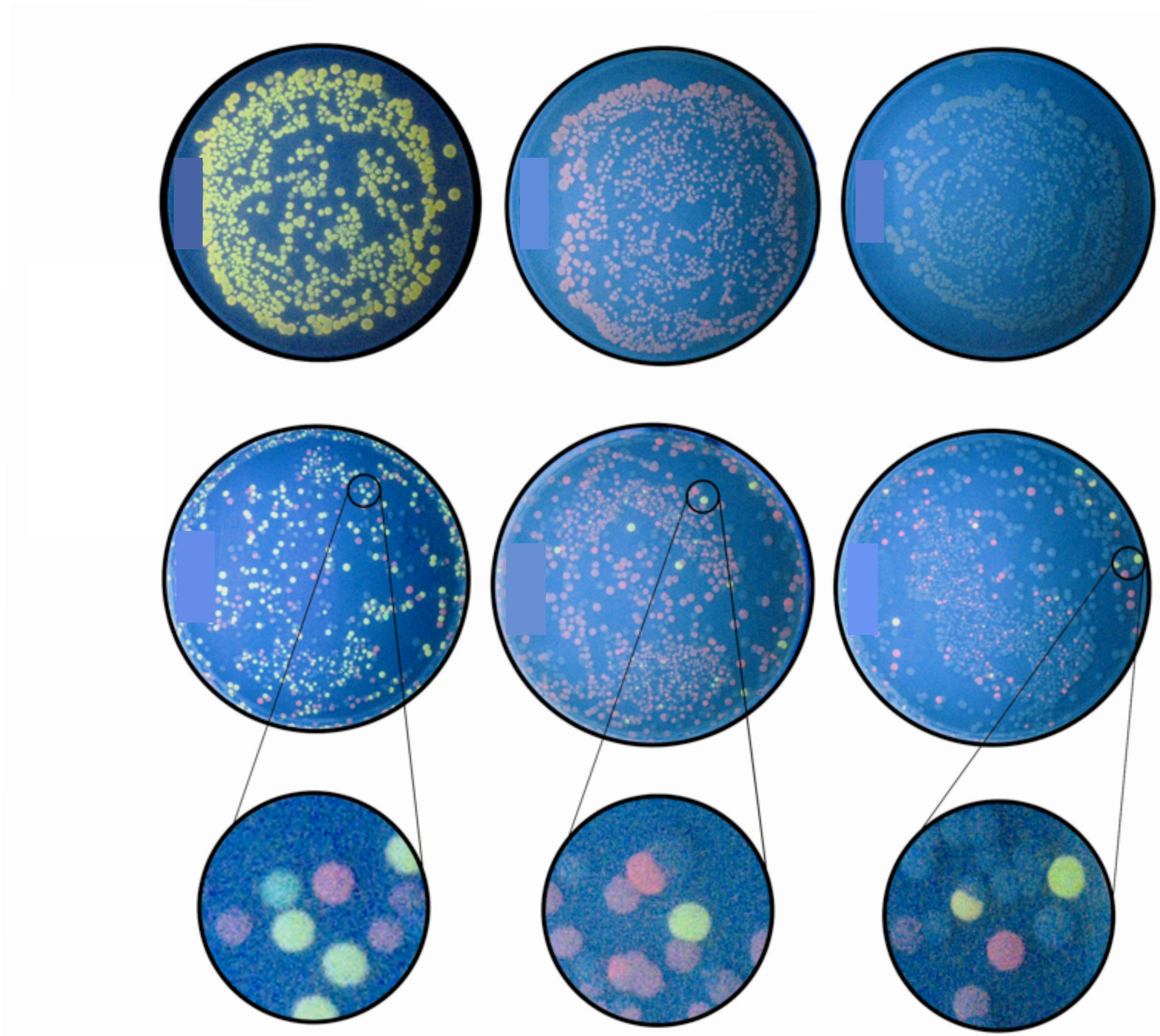
gcat.davidson.edu/GcatWiki/index.php/Davidson_Missouri_W/Davidson_Protocols

Engineering Biological HPP



Hin-mediated recombination

Bacteria Report Solutions



Unflipped

Flipped

Yellow colonies indicate solution found

Paper Published 7/09

JOURNAL OF BIOLOGICAL ENGINEERING

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Paper of the year, 2009

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1.
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Accesses

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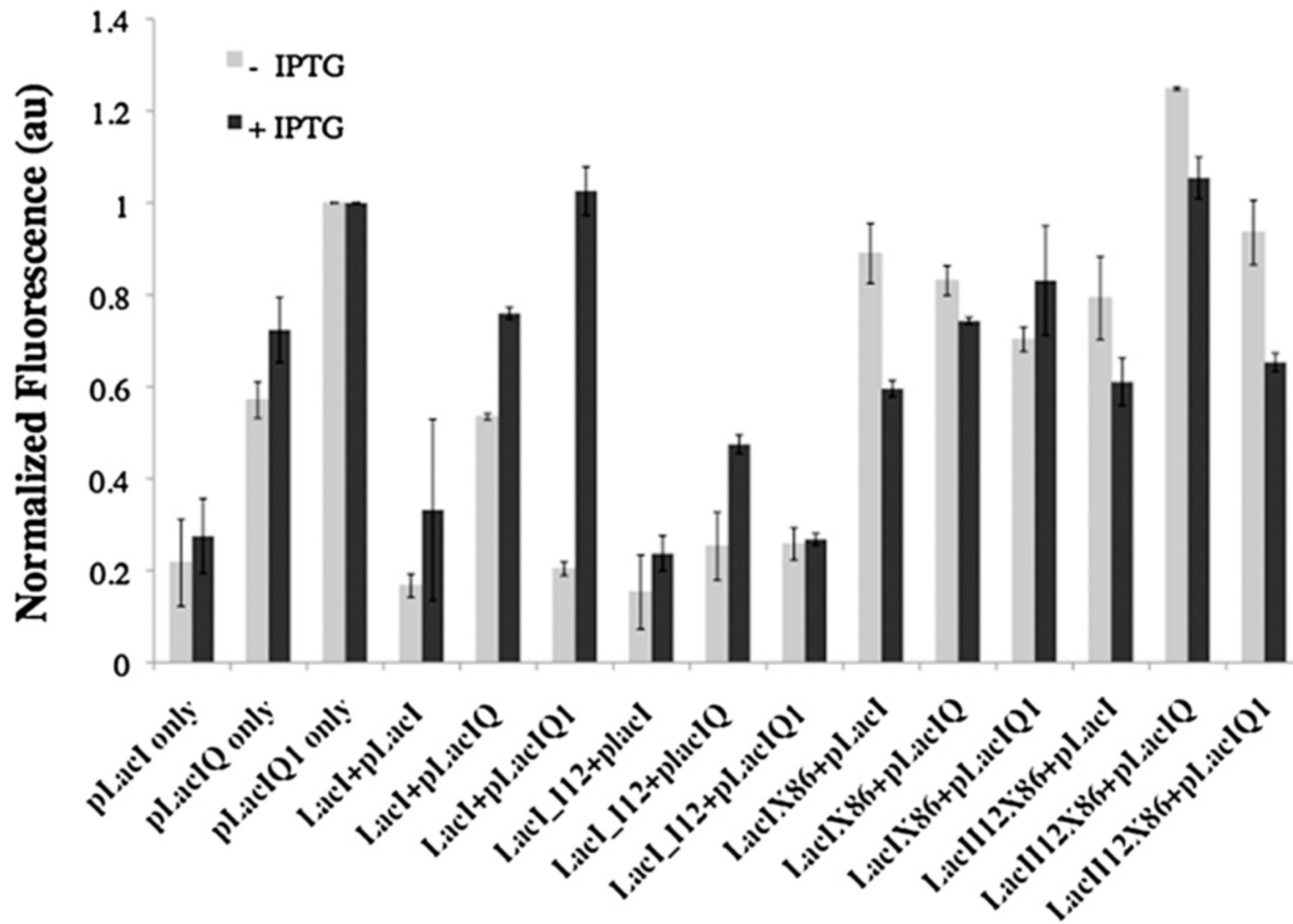
Solving a Hamiltonian Path Problem with a bacterial computer
Jordan Baumgardner, Karen Acker, Oyinade Adefuye, Samuel Crowley, Will DeLoache, James O Dickson, Lane Heard, Andrew T Martens, Nickolaus Morton, Michelle Ritter, Amber Shoecraft, Jessica Treece, Matthew Unzicker, Amanda Valencia, Mike Waters, A Malcolm Campbell, Laurie J Heyer, Jeffrey L Poet, Todd T Eckdahl
Journal of Biological Engineering 2009, **3**:11 (24 July 2009)
Abstract | Full text | PDF | PubMed | F1000 Biology | Editor's summary

15 undergraduate coauthors

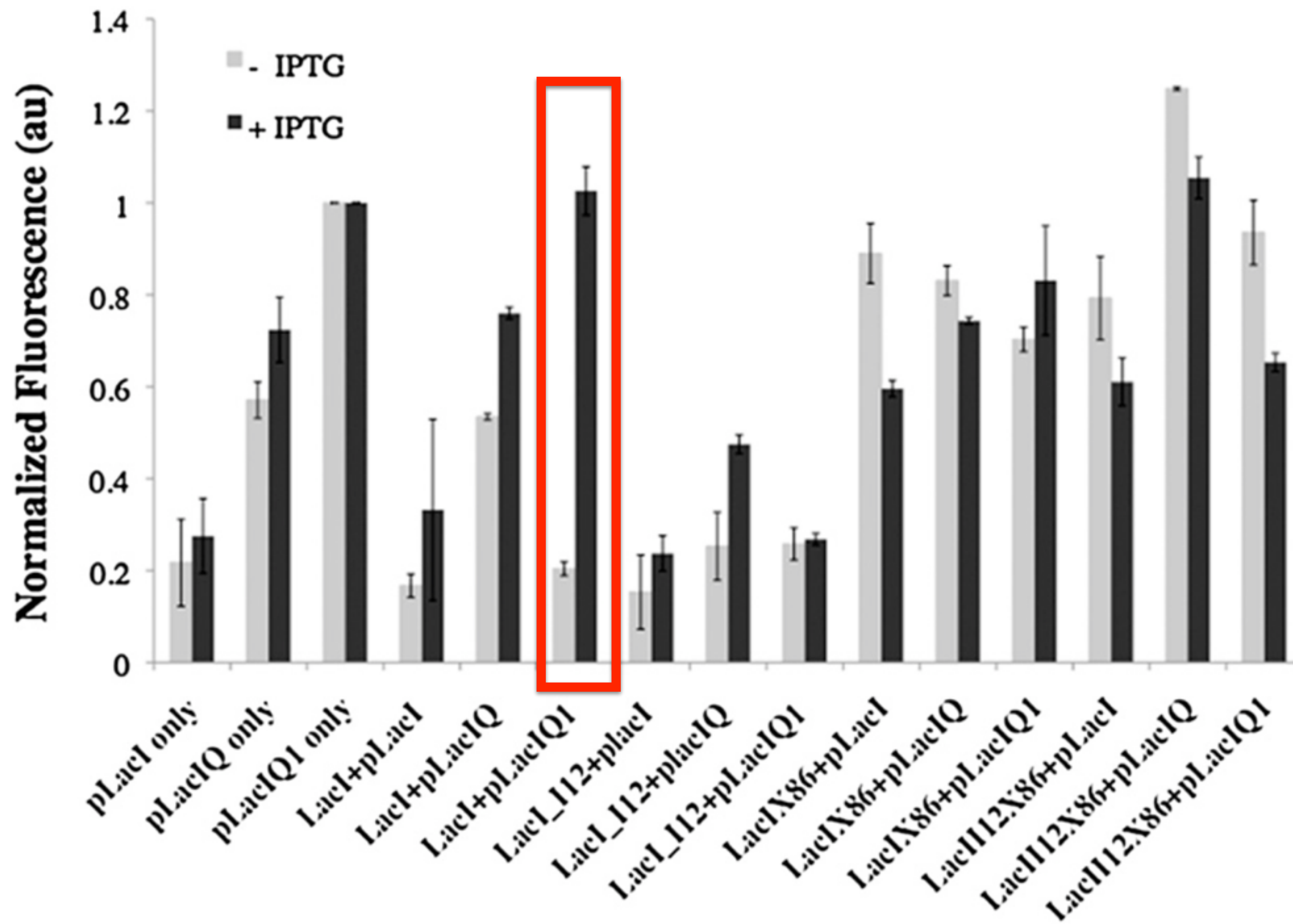
Improving the Lac system for synthetic biology

Pallavi Penumetcha[1], Kin Lau[1], Xiao Zhu[2], Kelly Davis[1], Todd T. Eckdahl[2,3], A. Malcolm Campbell[1,3]



Improving the Lac system for synthetic biology

Pallavi Penumetcha[1], Kin Lau[1], Xiao Zhu[2], Kelly Davis[1], Todd T. Eckdahl[2,3], A. Malcolm Campbell[1,3]

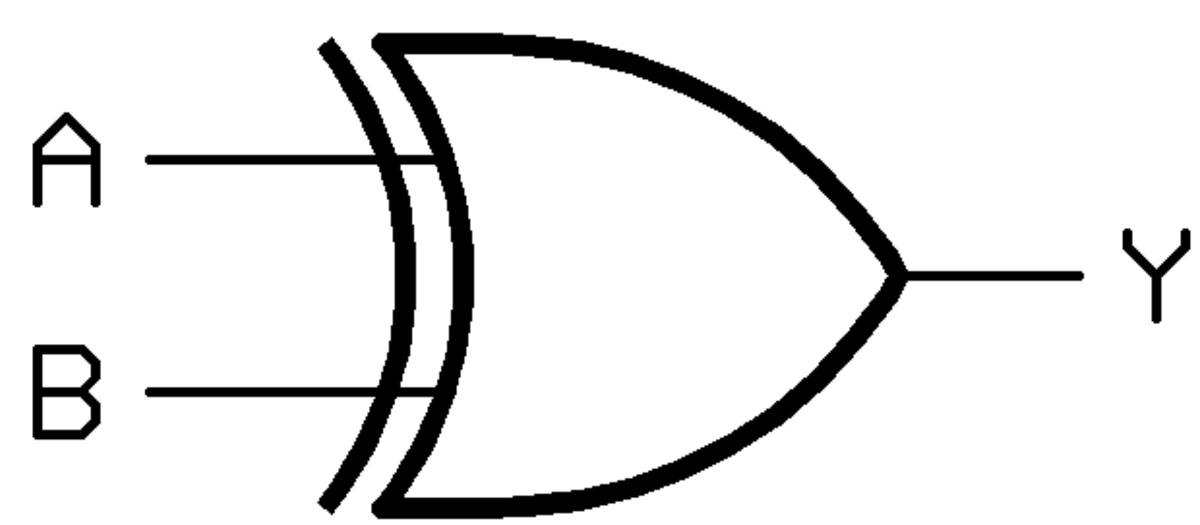


Can Bacteria Perform Hash Function?

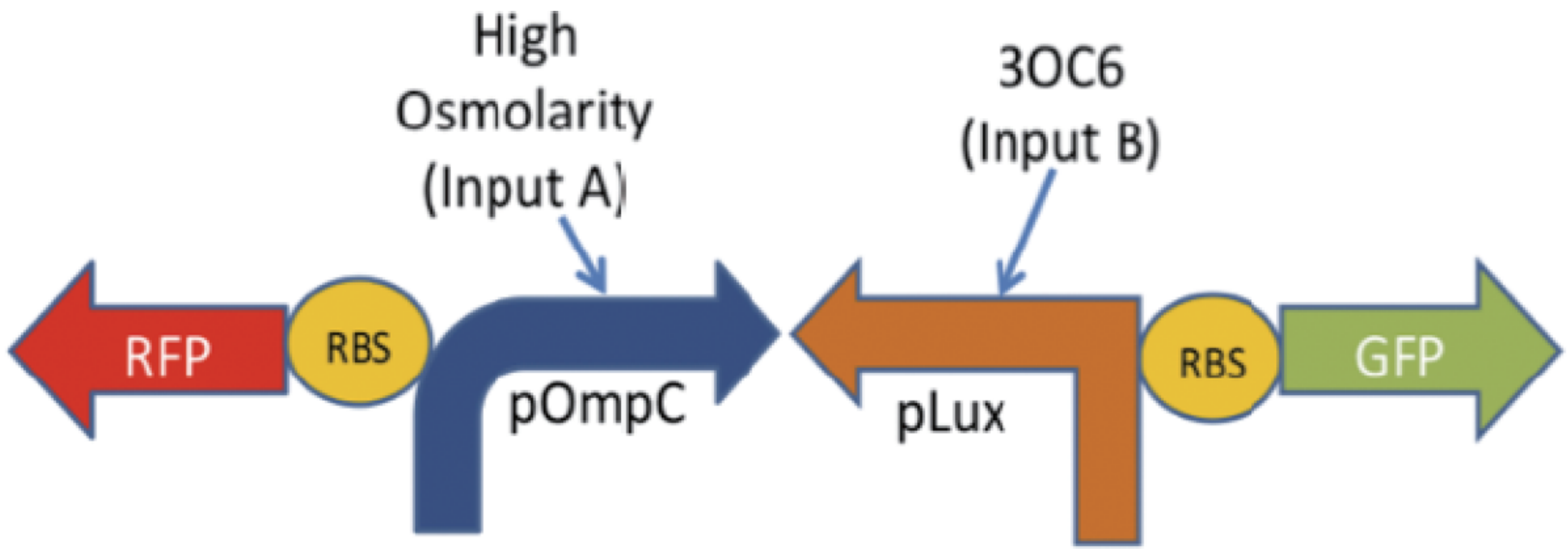
HGTf34$2

Use XOR Logic Gate for Hash Function

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

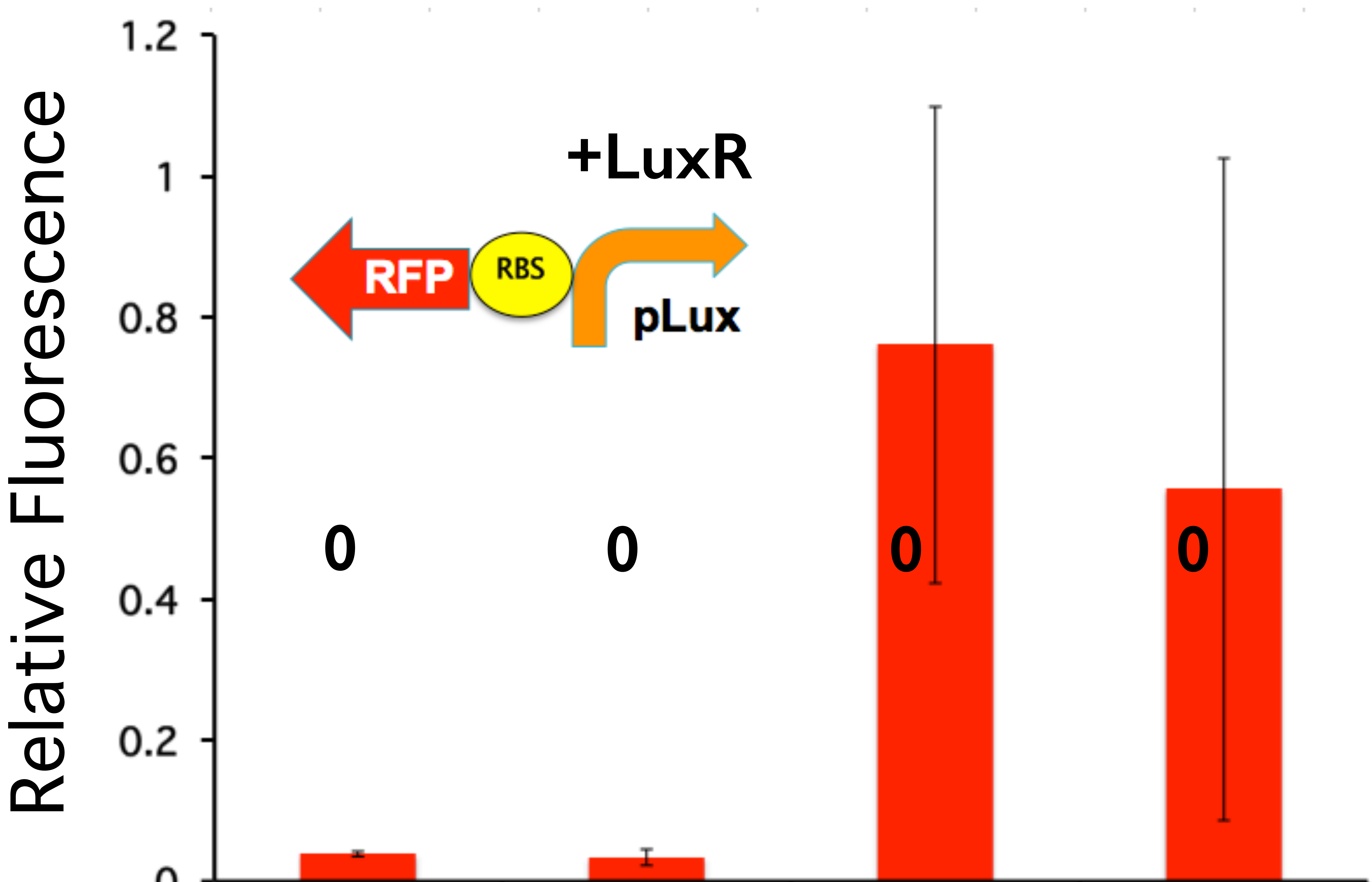


DNA XOR Logic Gate



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

pLux + LuxR Promotes Backwards



LuxR	-	-	+	+
3OC6	-	+	-	+

Published 2011, 17 students

Journal Article Synopsis

IBC 2011, vol. 3, article no. 10, pp. 1-10 | doi: 10.4051/ibc.2011.3.3.0010

Reports on negative result (Synthetic biology, Biological computation/Database, Biomathematics/Mathematical Biology and Medicine)

Open Access, Open Review

Bacterial Hash Function Using DNA-Based XOR Logic Reveals Unexpected Behavior of the LuxR Promoter

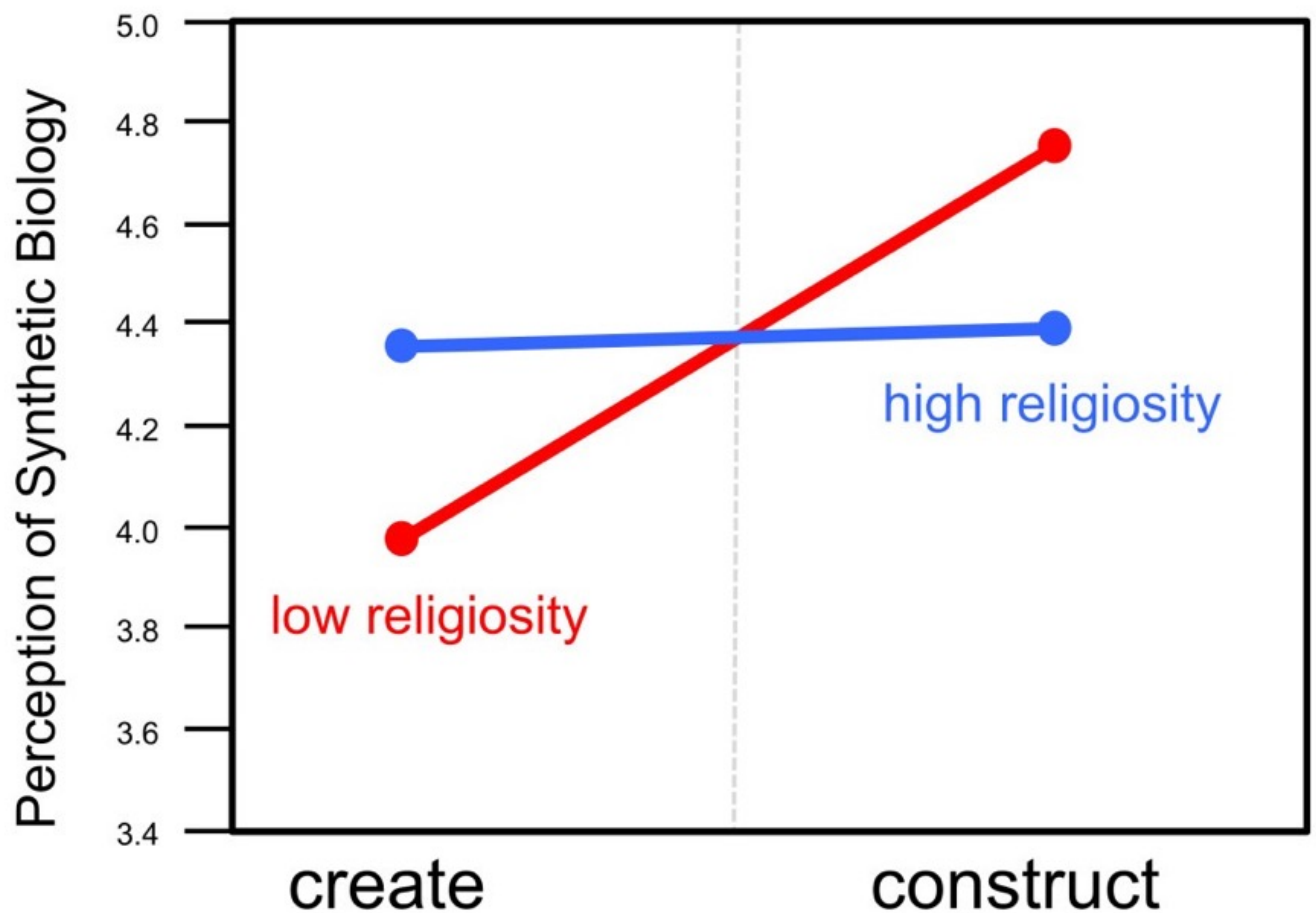
Brianna Pearson[1+], Kin H. Lau[1+], Alicia Allen[2], James Barron[1,3], Robert Cool[2], Kelly Davis[4], Will DeLoache[1], Erin Feeney[1], Andrew Gordon[2], John Igo[5], Aaron Lewis[5], Kristi Muscalino[4], Madeline Parra[4], Pallavi Penumetcha[1], Victoria G. Rinker[1,6], Karlesha Roland[1,7], Xiao Zhu[2], Jeffrey L. Poet[5,8], Todd T. Eckdahl[2,8], Laurie J. Heyer[4,8] and A Malcolm Campbell[1,8,*]

Word selection affects perceptions of synthetic biology

Brianna Pearson, Sam Snell, Kyri Bye-Nagel, Scott Tonidandel, Laurie J Heyer and A Malcolm Campbell

Journal of Biological Engineering 2011 5:9 | DOI: 10.1186/1754-1611-5-9 |

Received: 4 July 2011 | Accepted: 21 July 2011 | Published: 21 July 2011



3 students,
3 majors

IBC 2012, vol. 4, article no. 10, pp. 1-12 | doi: 10.4051/ibc.2012.4.3.0010

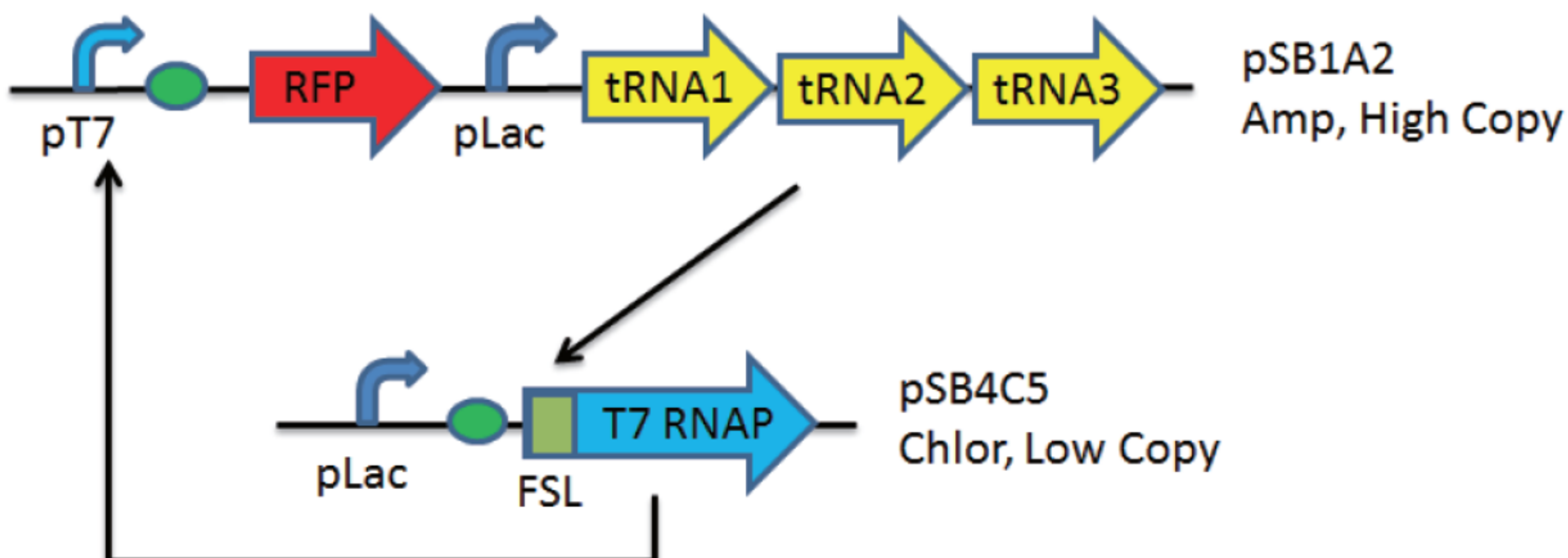
Reports on negative result (Synthetic biology, Biological computation/Database, Biomathematics/Mathematical Biology and Medicine)

Open Access, Open Review

Bacterial Logic Devices Reveal Unexpected Behavior of Frameshift Suppressor tRNAs

18 students

Eric M. Sawyer[1,2], Cody Barta[2], Romina Clemente[1], Michel Conn[2], Clif Davis[2], Catherine Doyle[1], Mary Gearing[1], Olivia Ho-Shing[1], Alyndria Mooney[1,3], Jerrad Morton[2], Shamita Punjabi[1], Ashley Schnoor[4], Siya Sun[4], Shashank Suresh[5], Bryce Szczepanik[2], D. Leland Taylor[1], Annie Temmink[5], William Vernon[2], A. Malcolm Campbell[1], Laurie J. Heyer[5], Jeffrey L. Poet[4] and Todd Eckdahl[2,*]



2015 *PLoS ONE*, 49 students

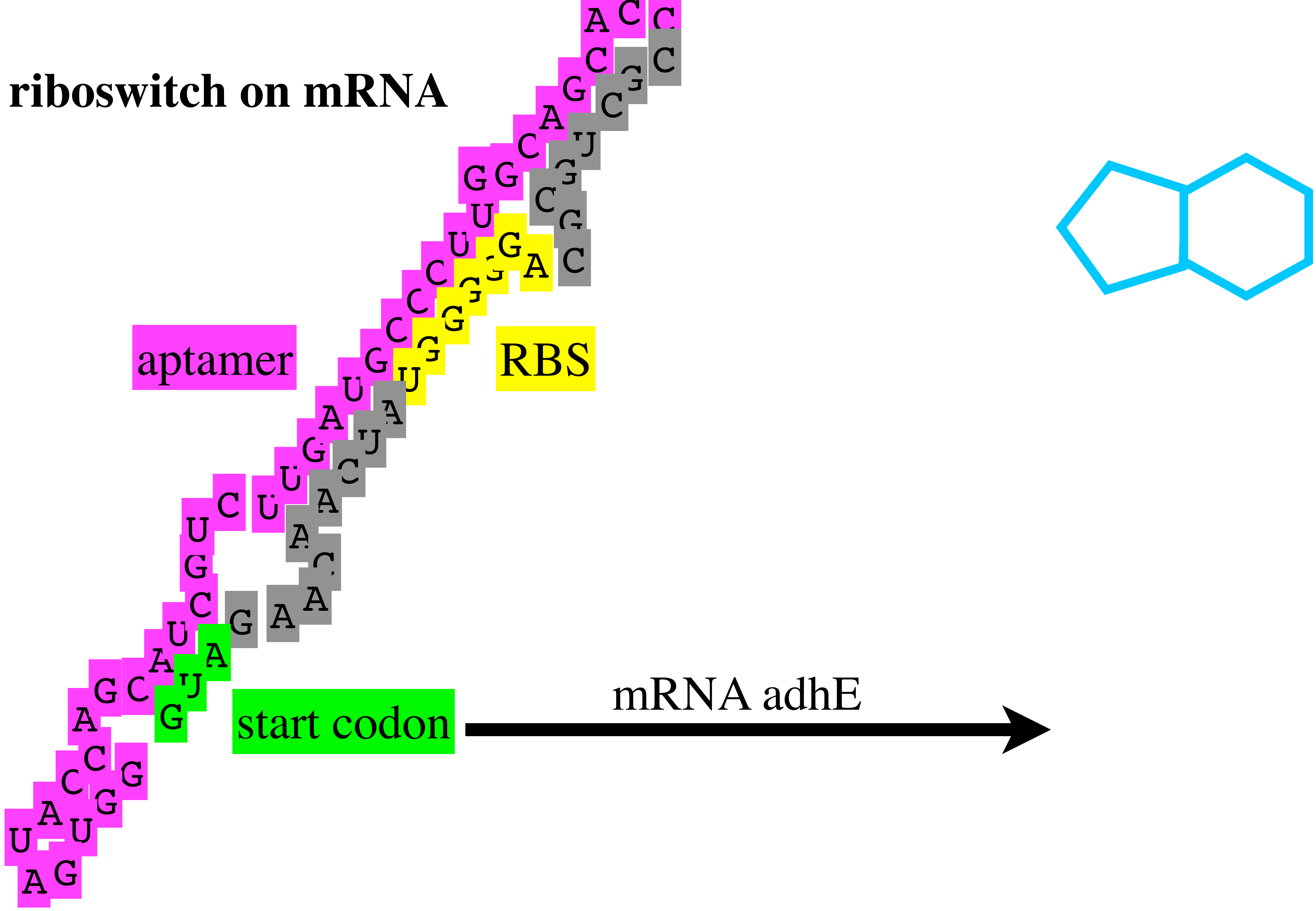
Programmed Evolution for Optimization of Orthogonal Metabolic Output in Bacteria

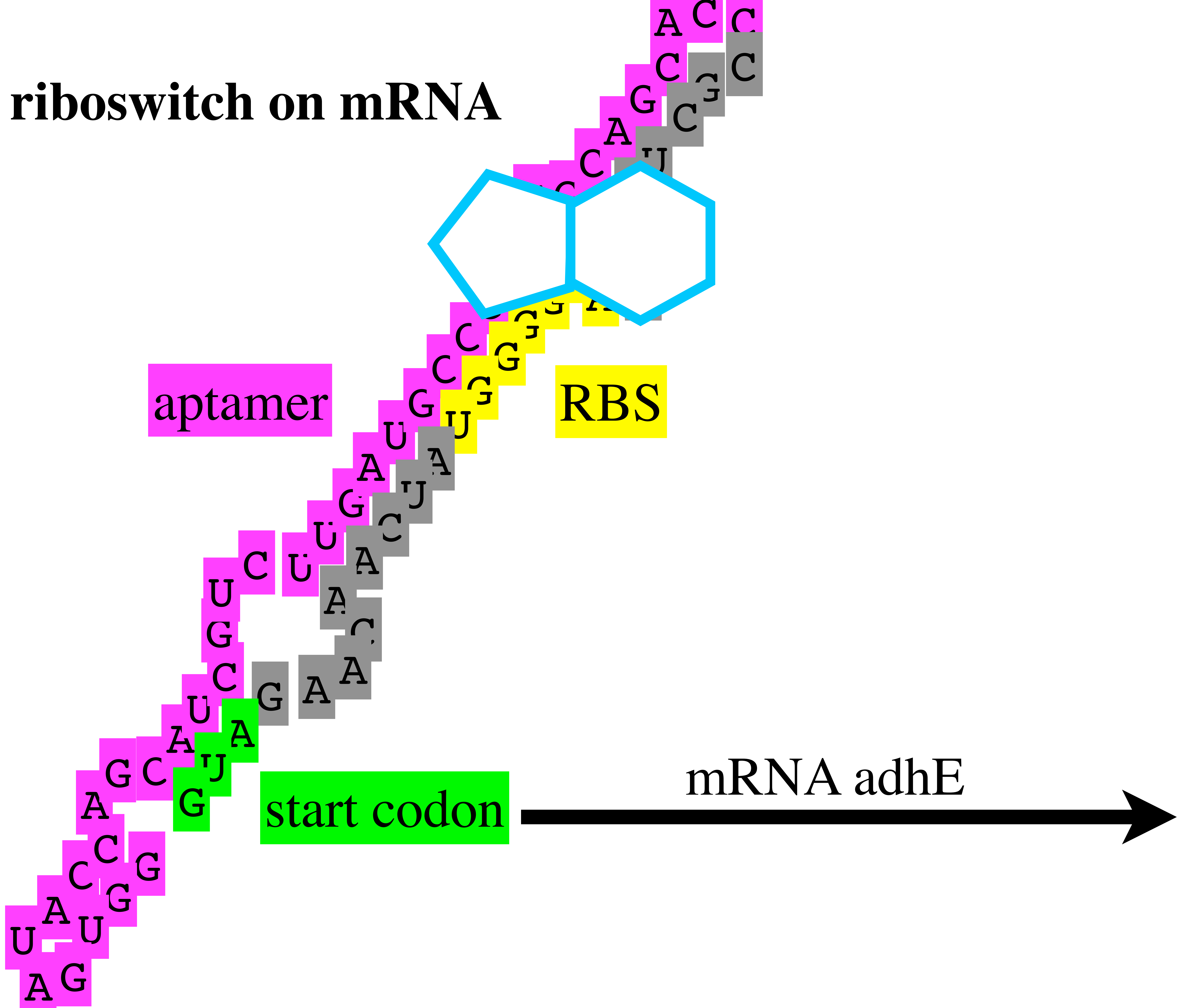
Todd T. Eckdahl[1]*, A. Malcolm Campbell[2], Laurie J. Heyer[3], Jeffrey L. Poet[4], David N. Blauch[5], Nicole L. Snyder[5], Dustin T. Atchley[2], Erich J. Baker[2], Micah Brown[3], Elizabeth C. Brunner[2], Sean A. Callen[4], Jesse S. Campbell[1], Caleb J. Carr[1], David R. Carr[1], Spencer A. Chadinha[2], Grace I. Chester[4], Josh Chester[4], Ben R. Clarkson[2], Kelly E. Cochran[1], Shannon E. Doherty[2], Catherine Doyle[2], Sarah Dwyer[2], Linnea M. Edlin[4], Rebecca A. Evans[2], Taylor Fluharty[4], Janna Frederick[4], Jonah Galeota-Sprung[3], Betsy L. Gammon[2], Brandon Grieshaber[1], Jessica Gronniger[2], Katelyn Gutteridge[4], Joel Henningsen[4], Bradley Isom[4], Hannah L. Itell[2], Erica C. Keffeler[1], Andrew J. Lantz[3], Jonathan N. Lim[2], Erin P. McGuire[2], Alexander K. Moore[4], Jerrad Morton[1], Meredith Nakano[2], Sara A. Pearson[1], Virginia Perkins[4], Phoebe Parrish[2], Claire E. Pierson[1], Sachith Polpityaarachchige[1], Michael J. Quaney[1], Abagael Slattery[2], Kathryn E. Smith[2], Jackson Spell[3], Morgan Spencer[3], Telavive Taye[2], Kamay Trueblood[1], Caroline J. Vrana[2], E. Tucker Whitesides[3]

Bacteria as Analog Computers

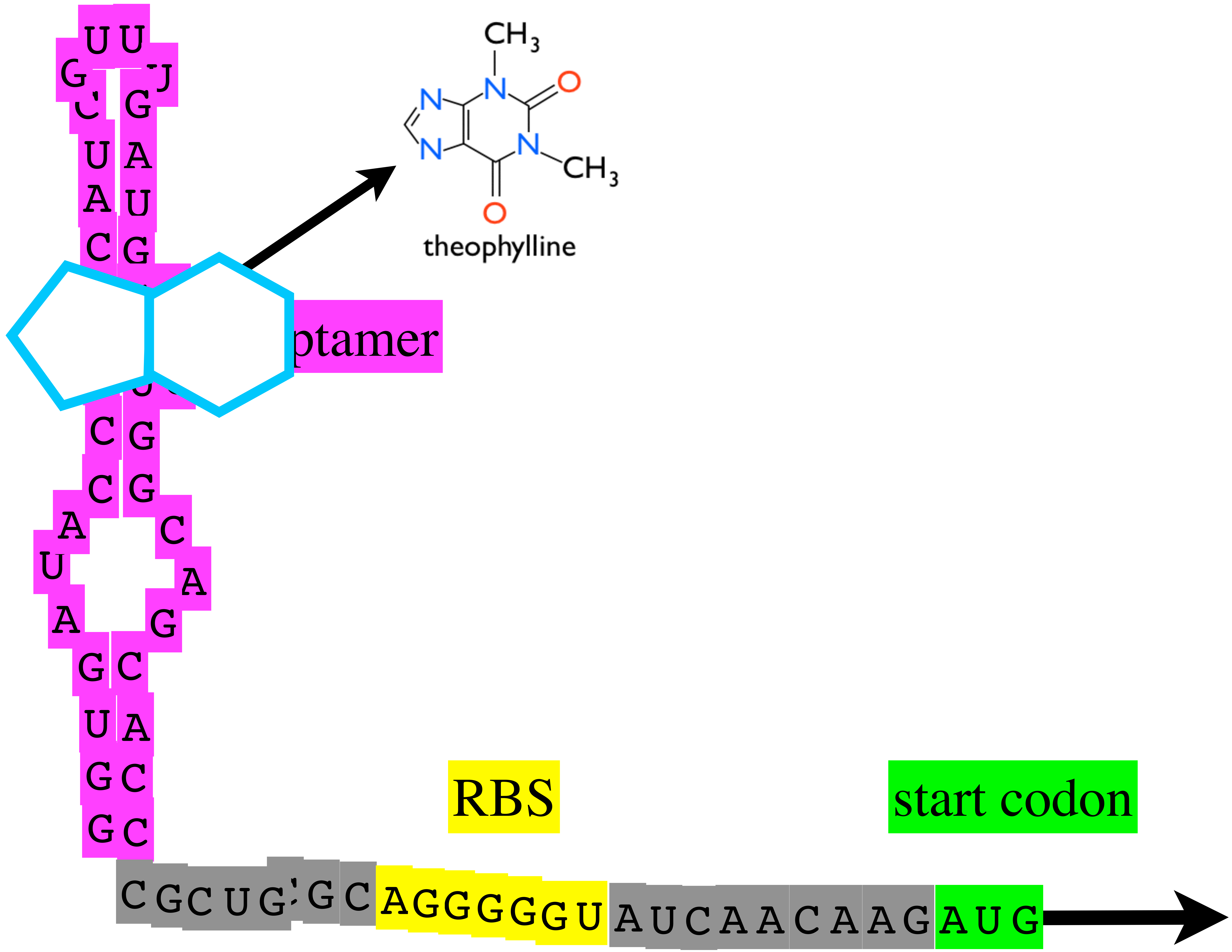
Promoter-RBS	Origin	Chaperone	Theophylline Production	Relative Fitness
RBS High-High	Low Copy	No Chaperone	0.44	1.00
RBS High-High	Low Copy	pTf16	0.35	0.49
RBS Low-Low	Low Copy	No Chaperone	0.43	0.10
RBS Low-Low	High Copy	No Chaperone	0.14	0.01
RBS High-High	Low Copy	pG-Tf2	0.19	0.00

riboswitch on mRNA





riboswitch on mRNA
aptamer
RBS
start codon
mRNA adhE



theophylline
ptamer
RBS
start codon
CGCUG GC AGGGGU AUCAACAAG AUG

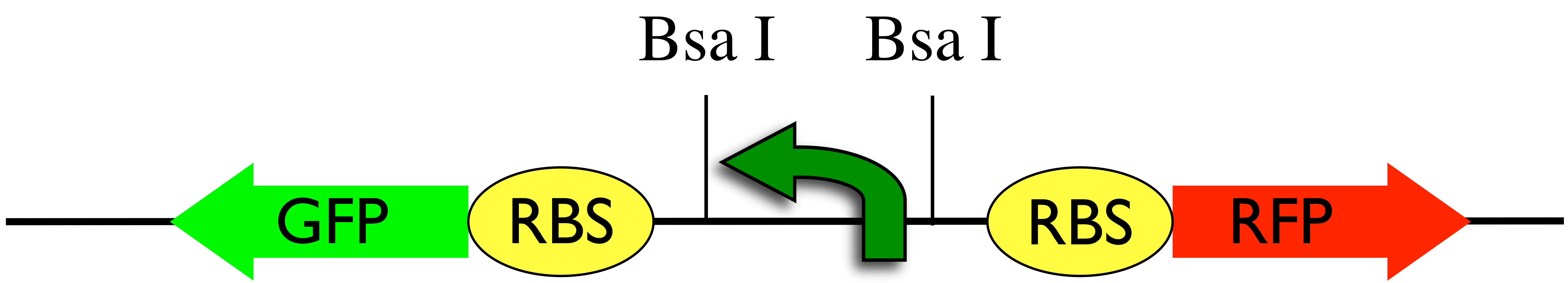
Can we bring real research into Introductory Biology?

Todd Eckdahl, MWSU

pClone: Synthetic Biology Tool Makes Promoter Research Accessible to Beginning Biology Students

A. Malcolm Campbell,* Todd Eckdahl,† Brian Cronk,‡ Corinne Andresen,† Paul Frederick,† Samantha Huckuntod,† Claire Shinneman,† Annie Wacker,* and Jason Yuan†

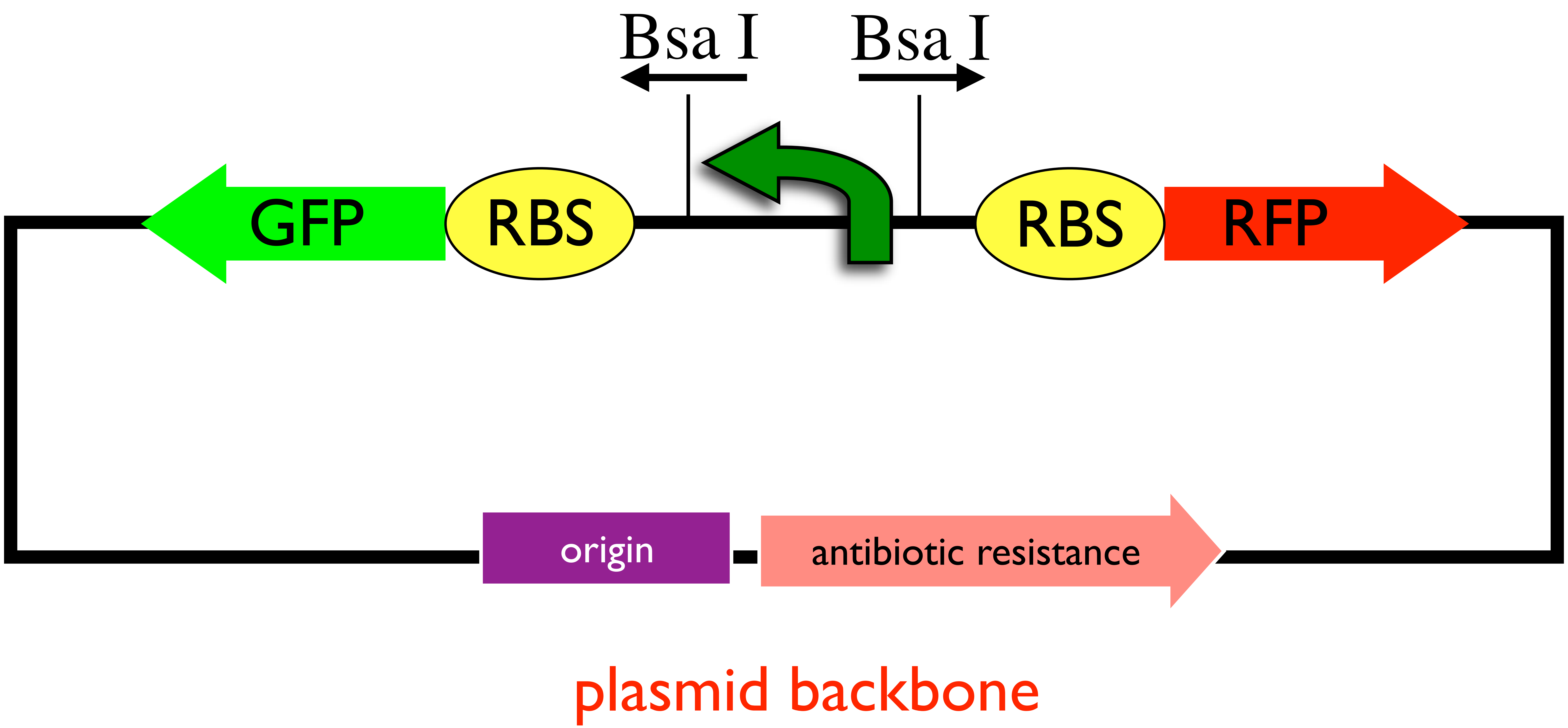
4 undergrads
2 HS students



Campbell, *et al.* 2014. *CBE Life Sciences Education*. Vol. 13(2): 285 - 296.

pClone Red

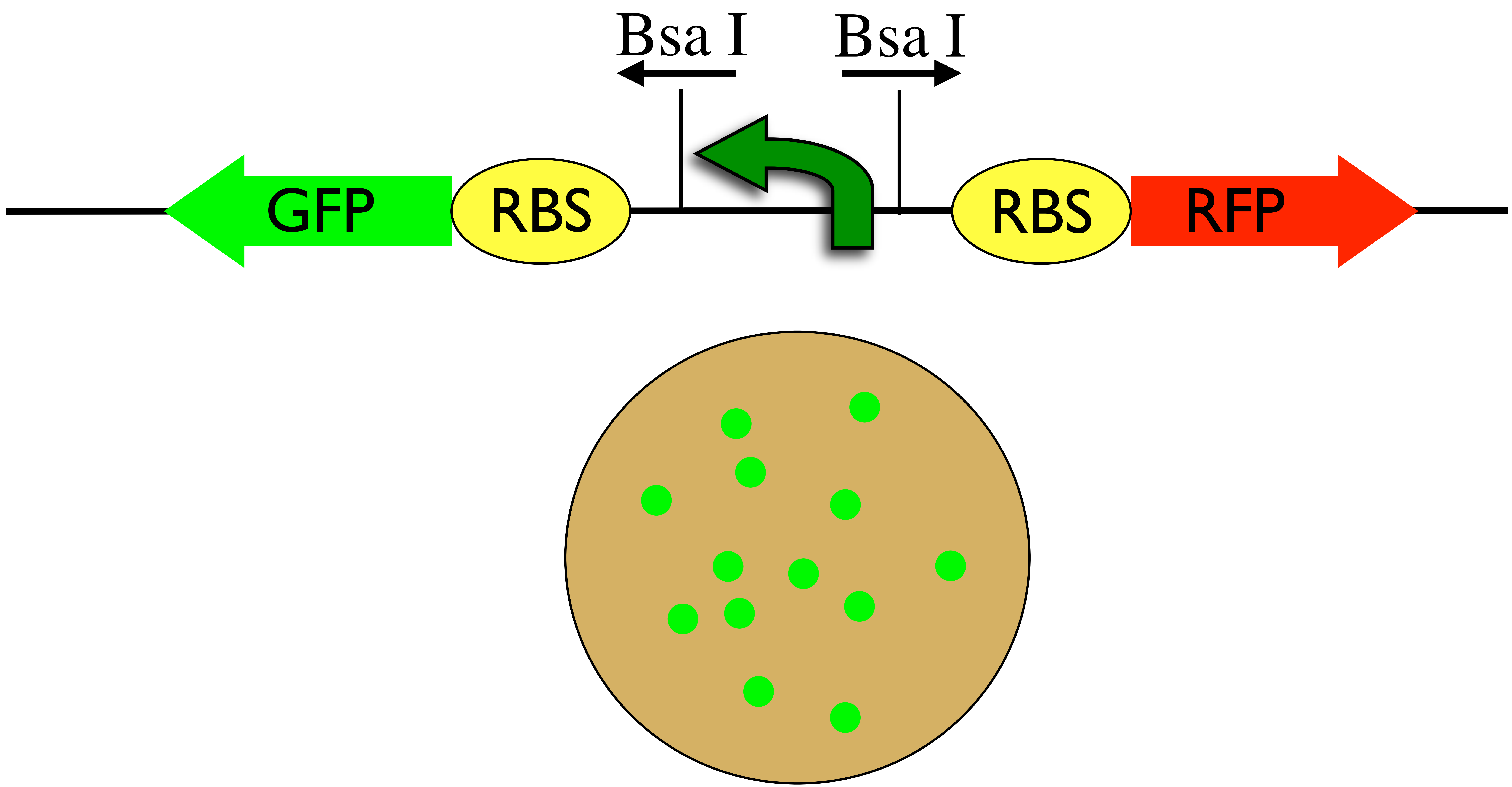
J119137



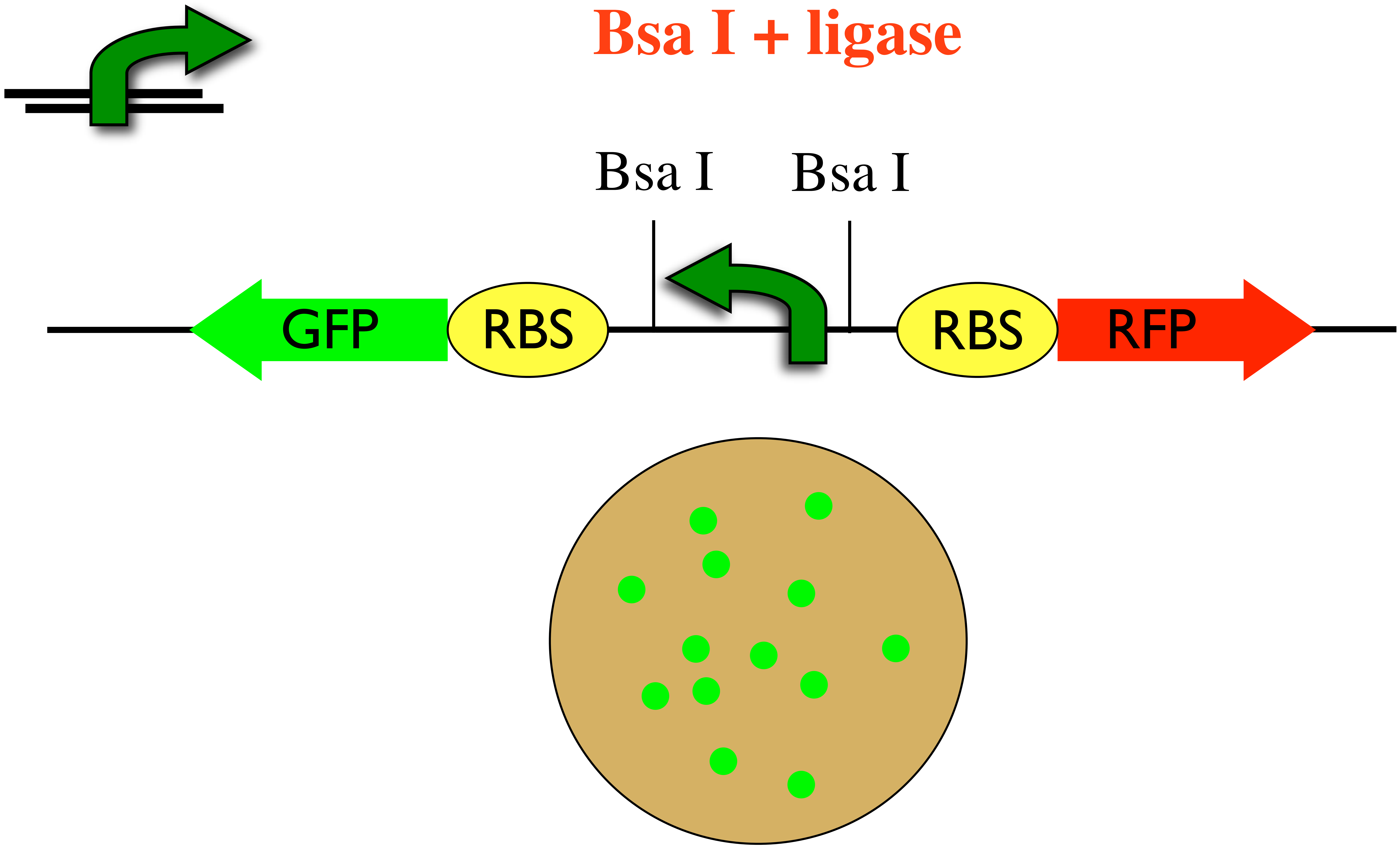
Campbell, *et al.* 2014. *CBE Life Sciences Education*. Vol. 13(2): 285 - 296.

pCloneRed

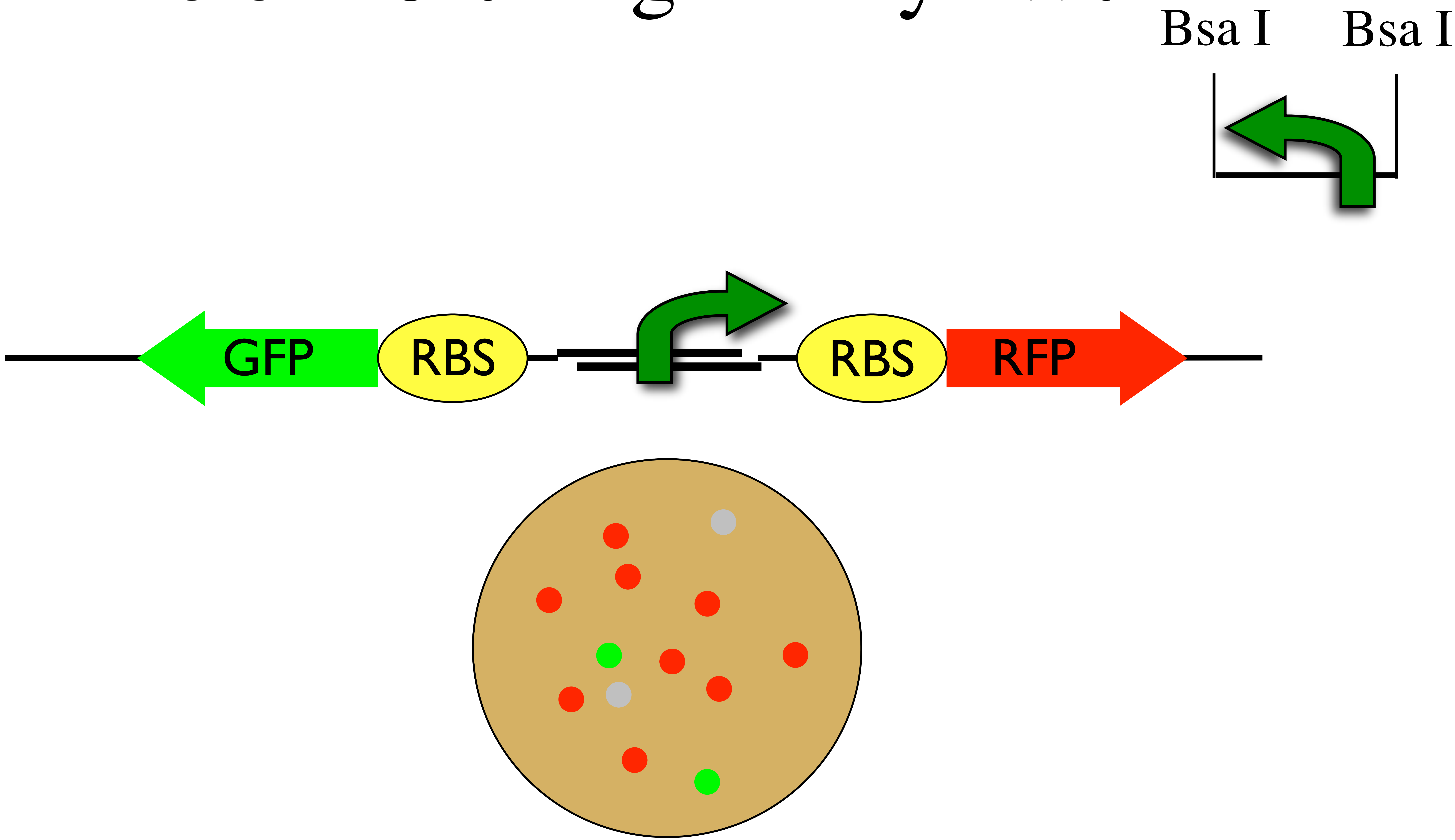
all colonies green



Golden Gate Assembly Method

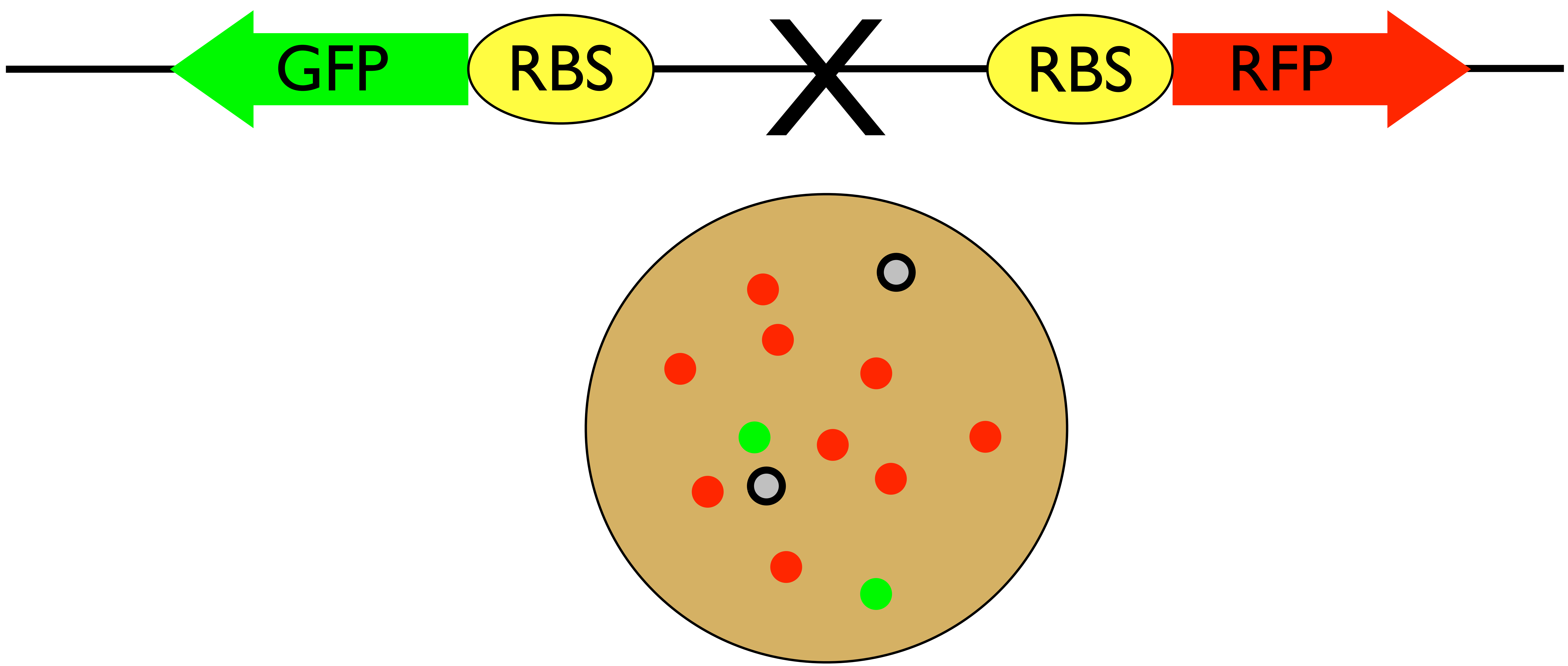


GGA Cloning Always Works



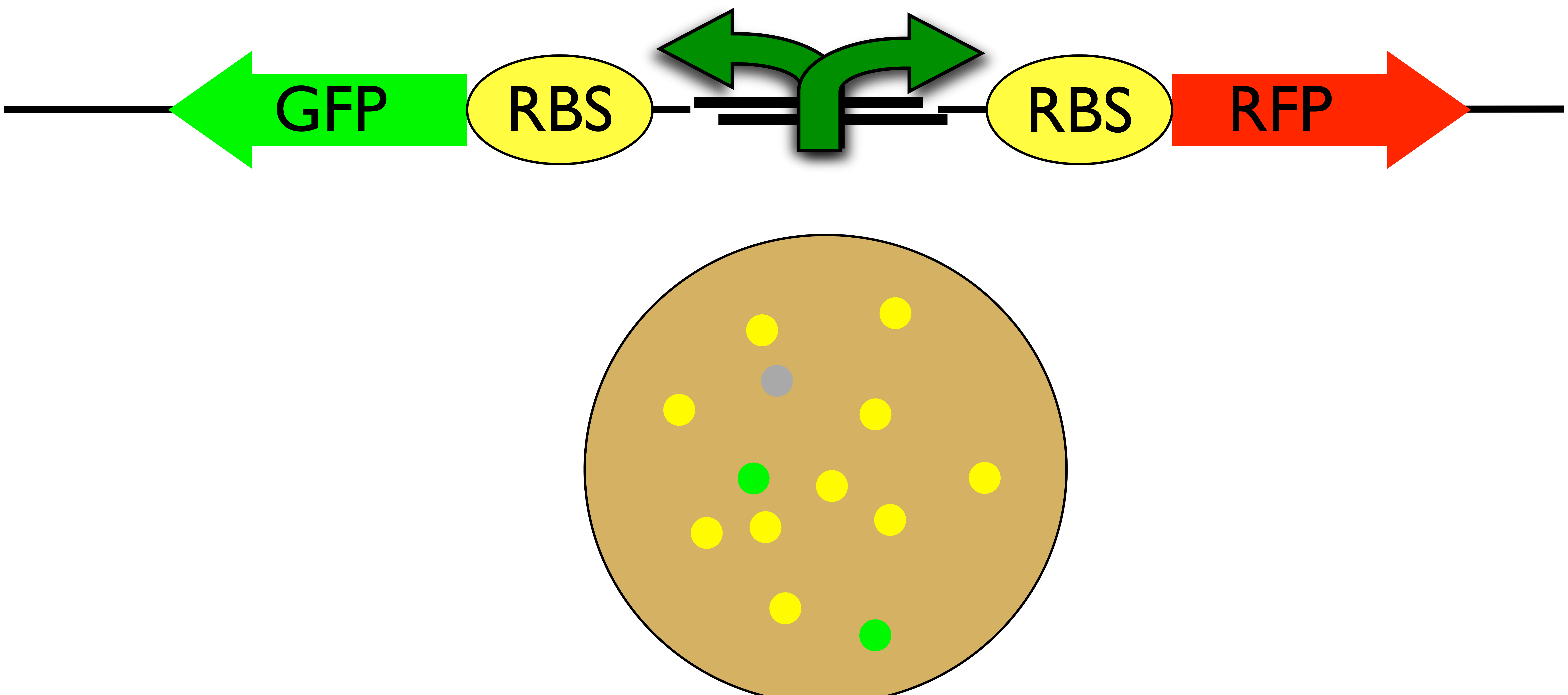
Remove Initial Promoter

J119137



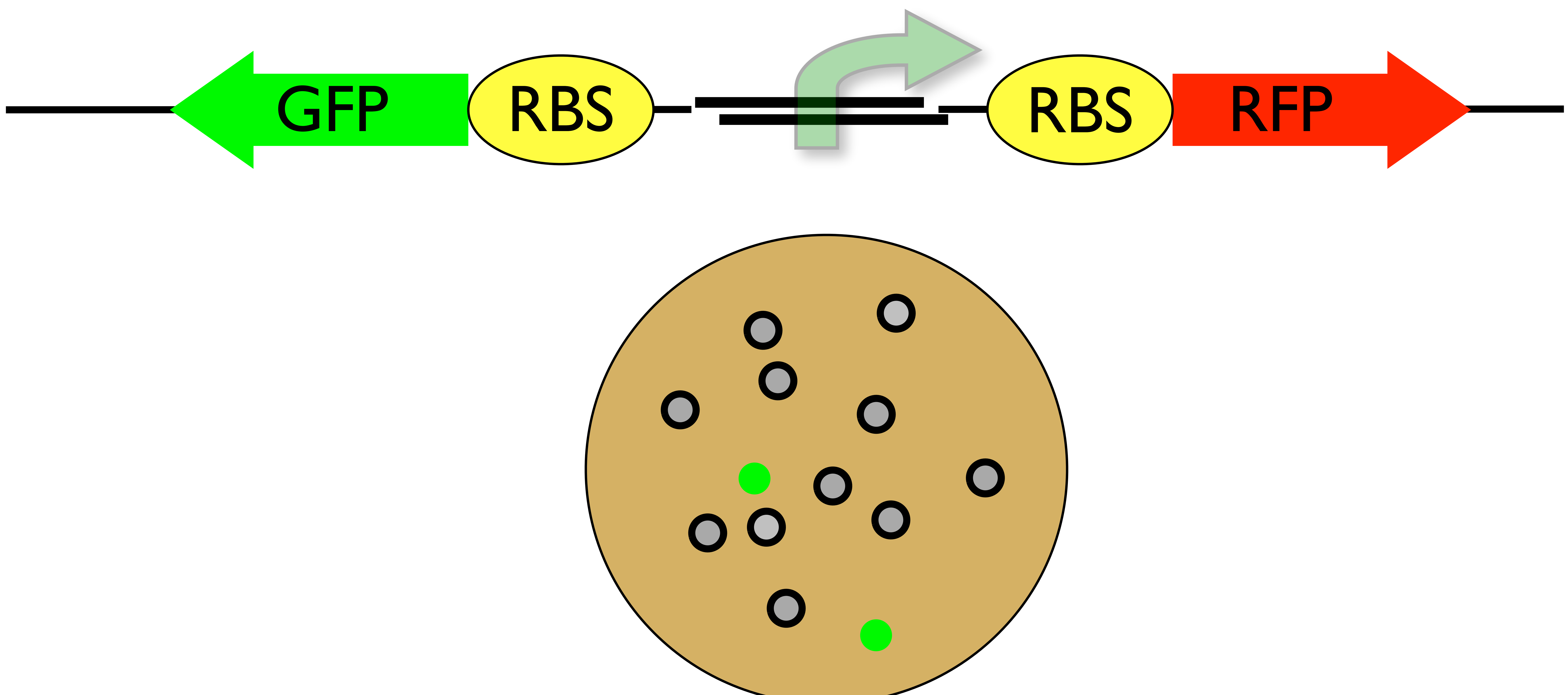
Insert Bi-directional Promoter

J119137



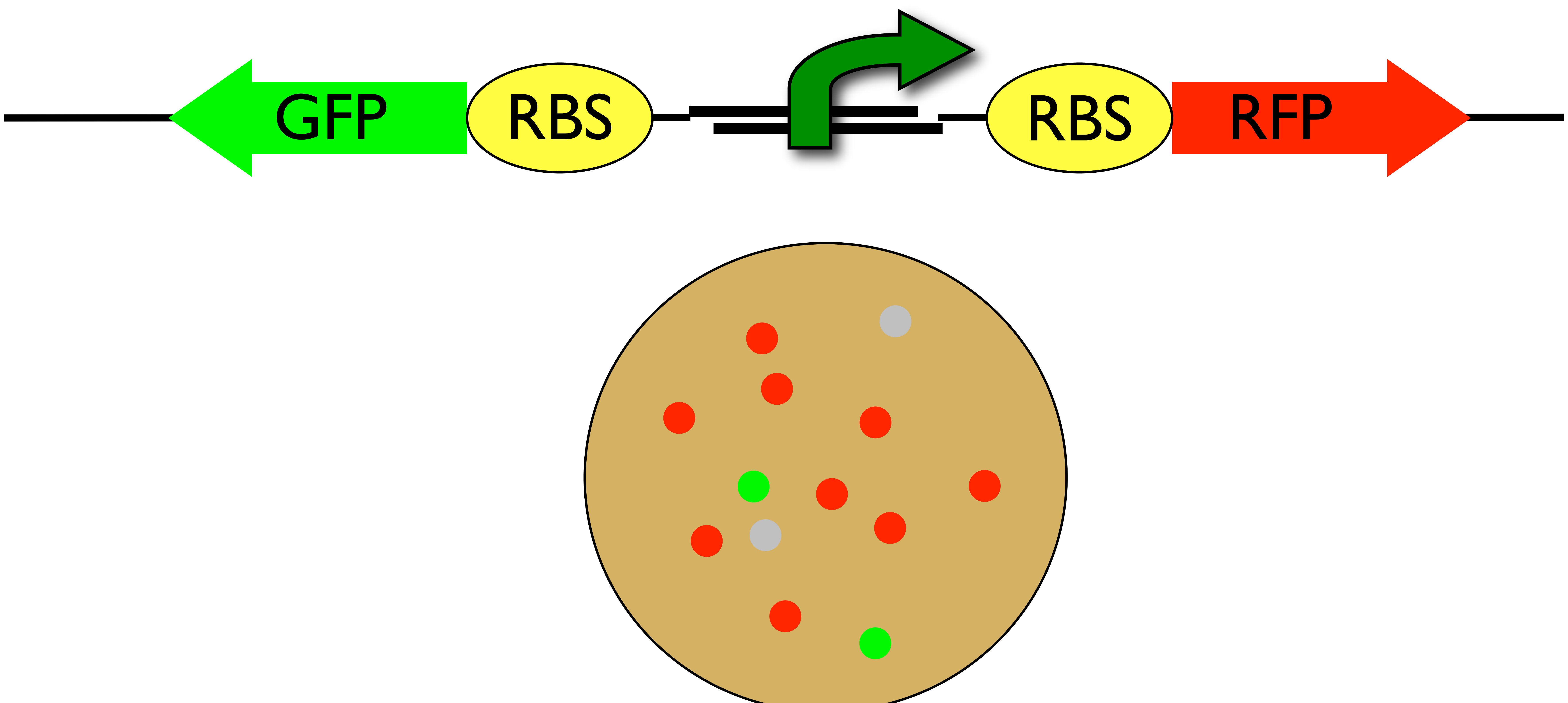
Insert Non-functional Promoter

J119137

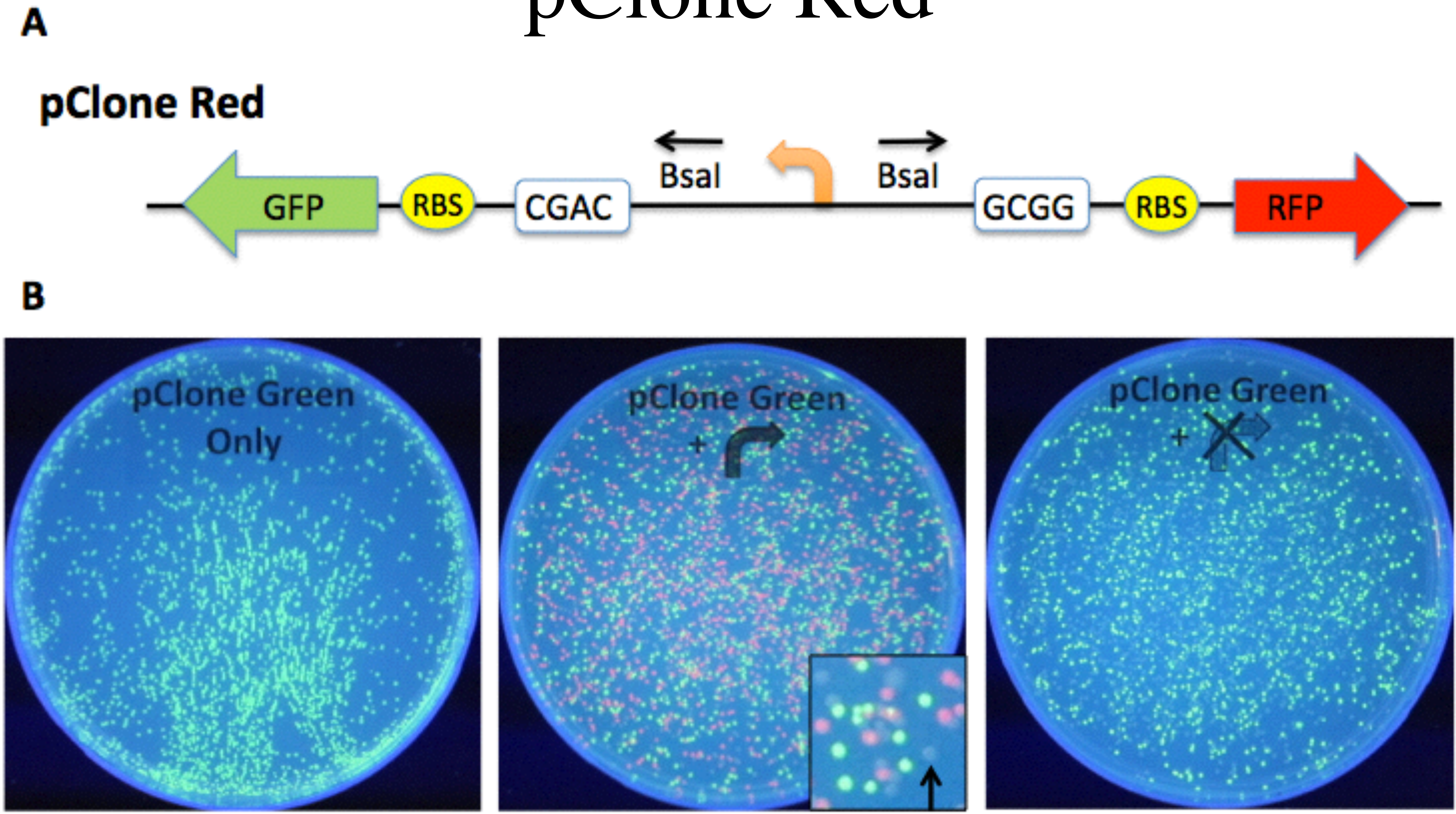


First Years in 3 Hour Lab: GGA

no gel purifications!

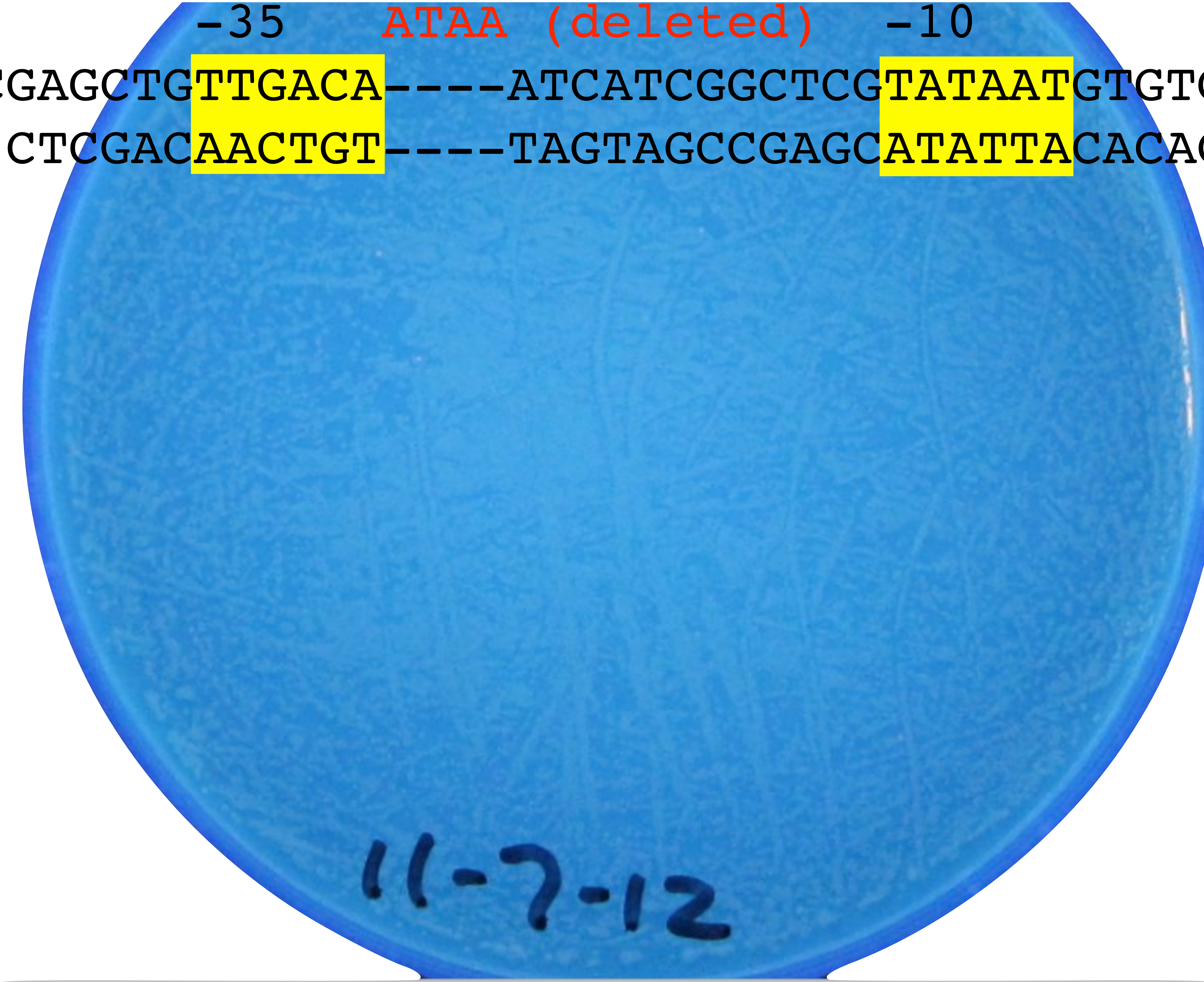


pClone Red

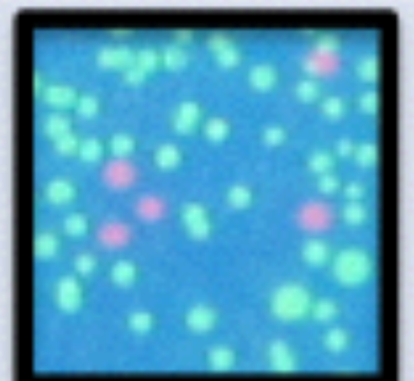
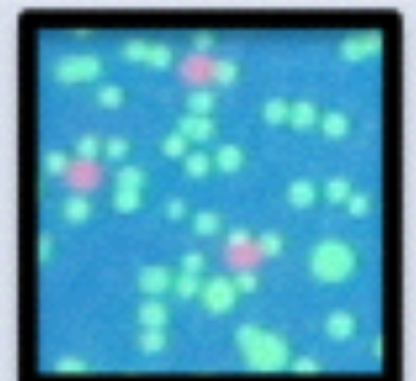
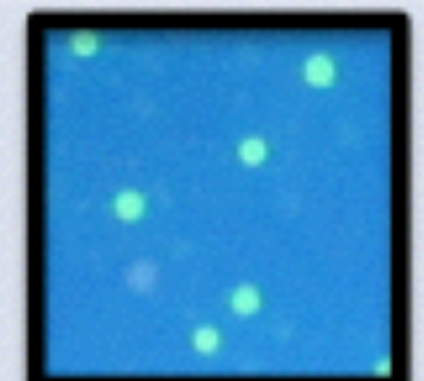
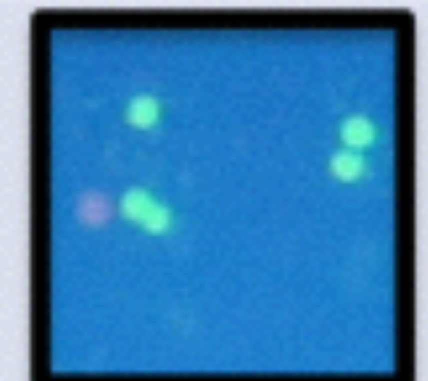
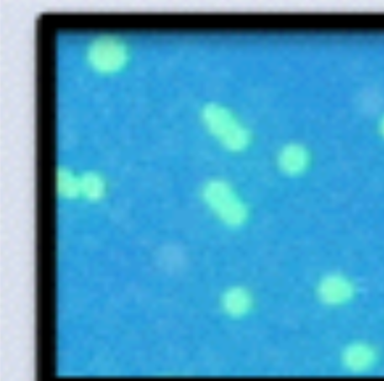
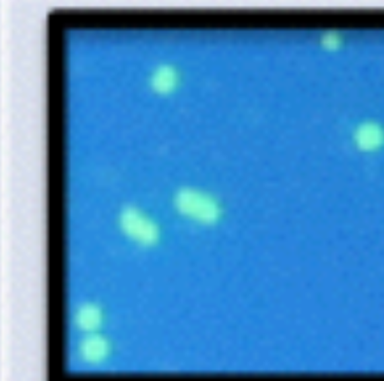
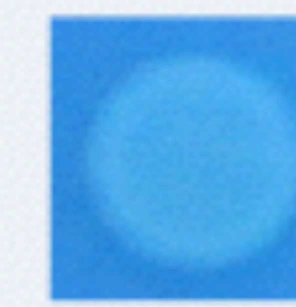

A
pClone Red
BsaI
BsaI
GFP
RBS
CGAC
GCGG
RBS
RFP
B
pClone Green
Only
pClone Green
+
pClone Green
+

Student Sample, November 2012

```
              -35    ATAA (deleted)   -10
5′ CGACGAGCTGTTGACA----ATCATCGGCTCGTATAATGTGTGGA     3′
3′       CTCGACAACTGT----TAGTAGCCGAGCATATTACACACCTCGCC 5′
```



Quantify with Phone and ImageJ

Mutant	J119319	J119320	J119321	J119322	J119323	J119324	J119325	J119326
pClone Green plate								
Isolated clones								
Expression Ratio	4.09	3.94	3.84	2.04	1.54	1.34	3.52	1.00

pClone: Exploring Promoters with Synthetic Biology

2 Items **Exclusive** $215.00 - $215.00 **View Details**

5 / 5

Give your students the opportunity to learn and explore transcription regulation right in your classroom. This unique approach to synthetic biology was developed by college professors focused on creating a unique activity to demonstrate gene regulation. This multi-part lab will expose students to cloning, restriction enzymes, transformation, microbiology, and so much more in an effective classroom protocol.

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Item #211150 Available 5/4/16

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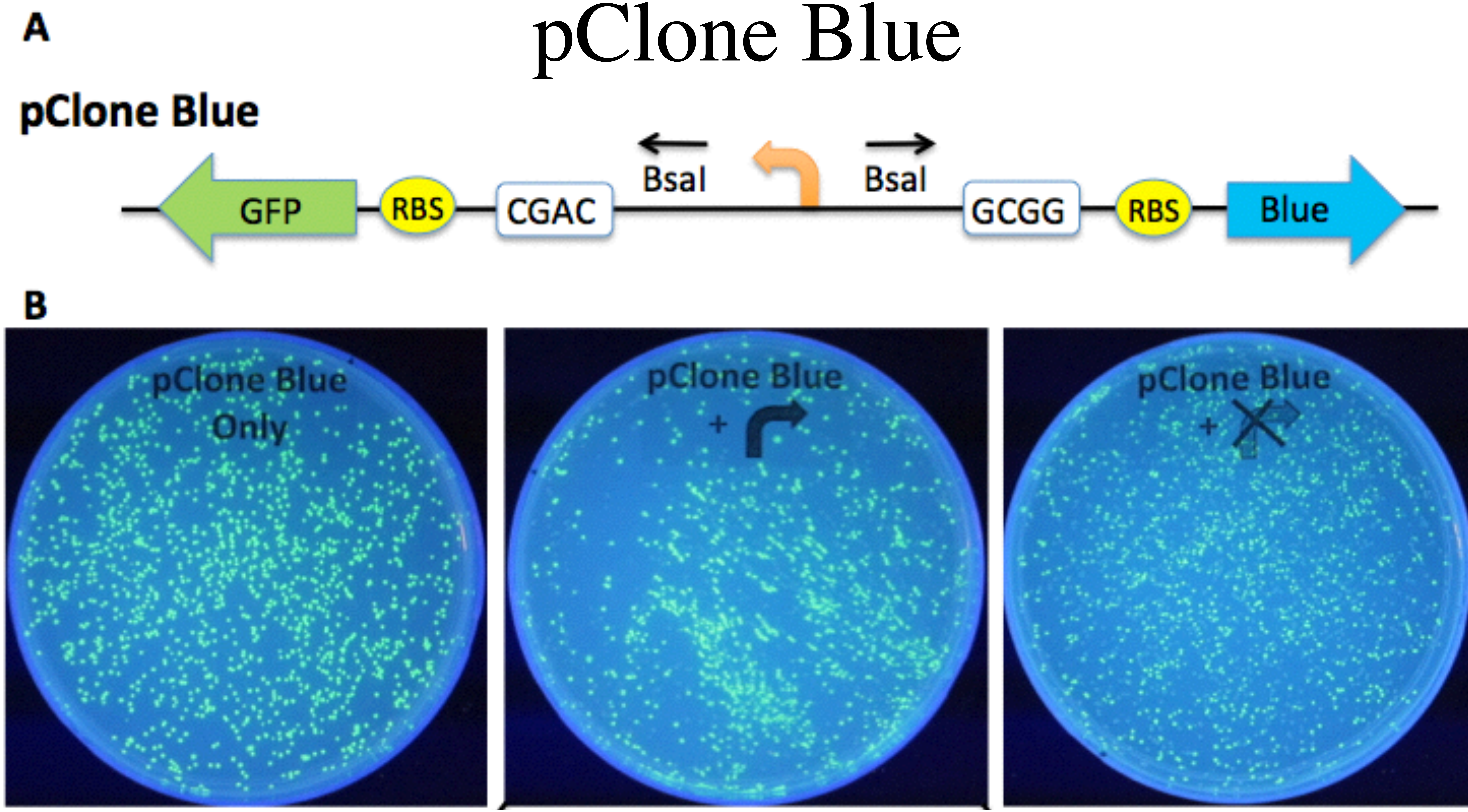
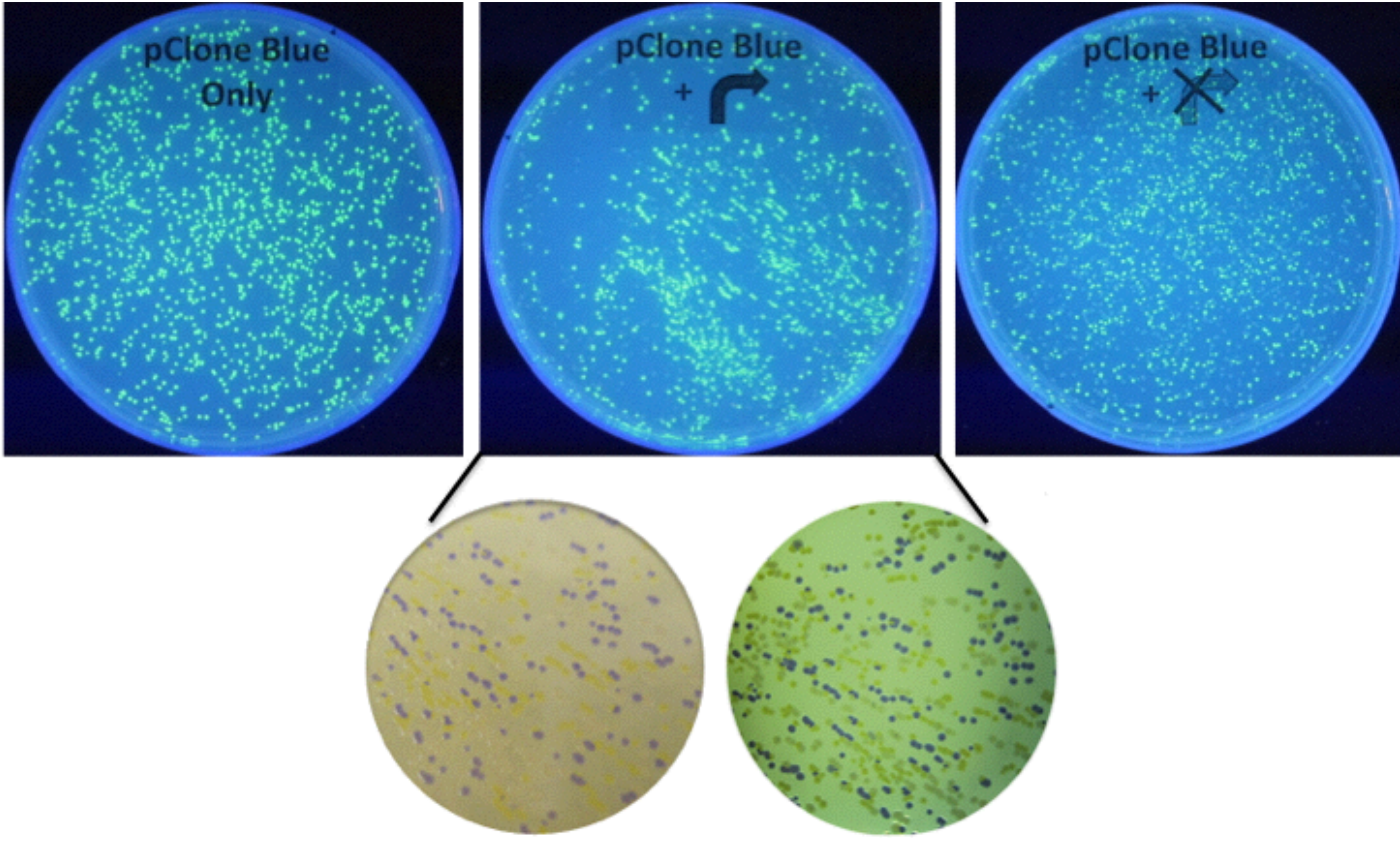
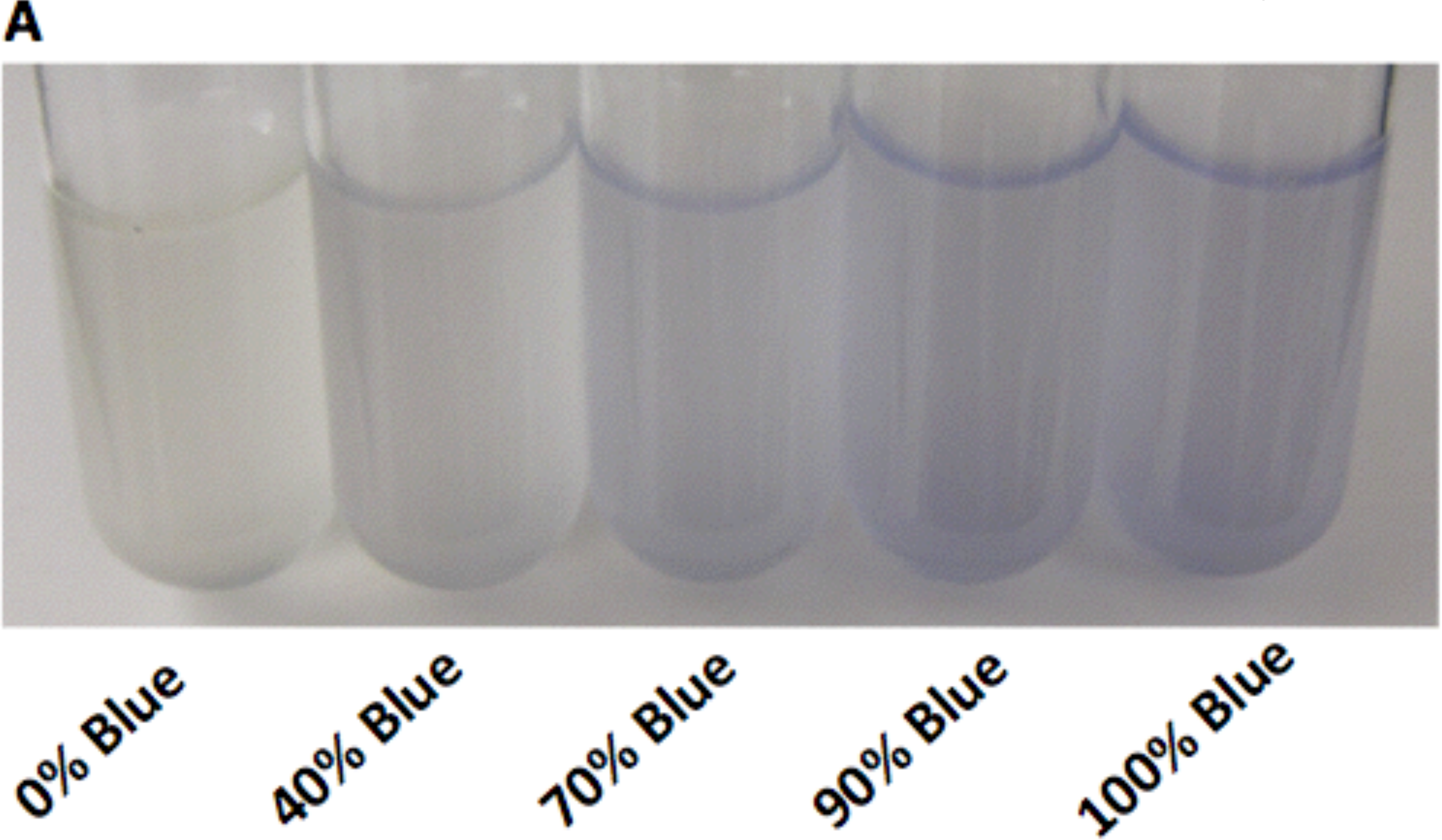
pClone Blue


A
pClone Blue
BsaI
BsaI
GFP
RBS
CGAC
GCGG
RBS
Blue
B
pClone Blue
Only
pClone Blue
+
pClone Blue
+

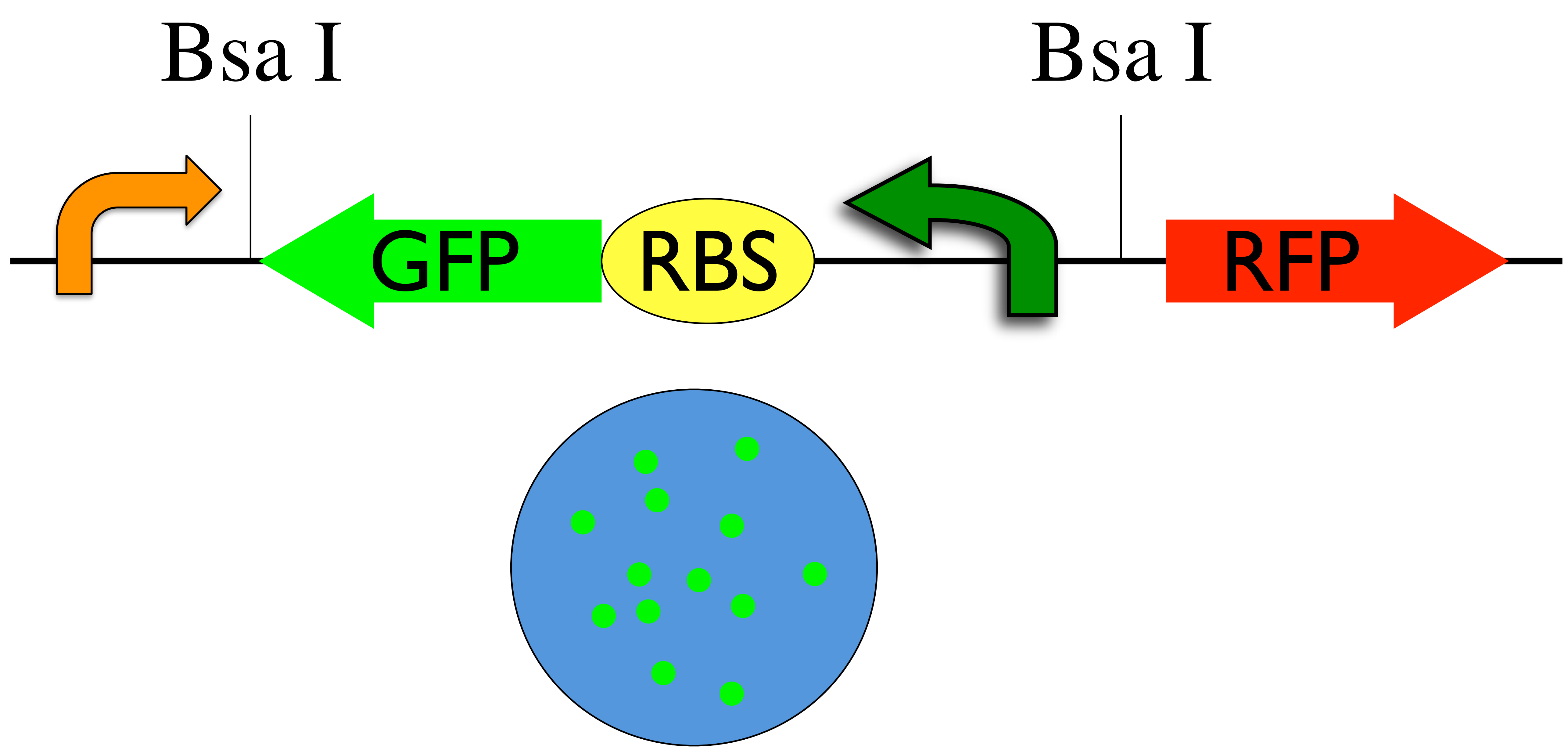

pClone Blue
Only
pClone Blue
+
pClone Blue
+

Measure Promoter Qualitatively



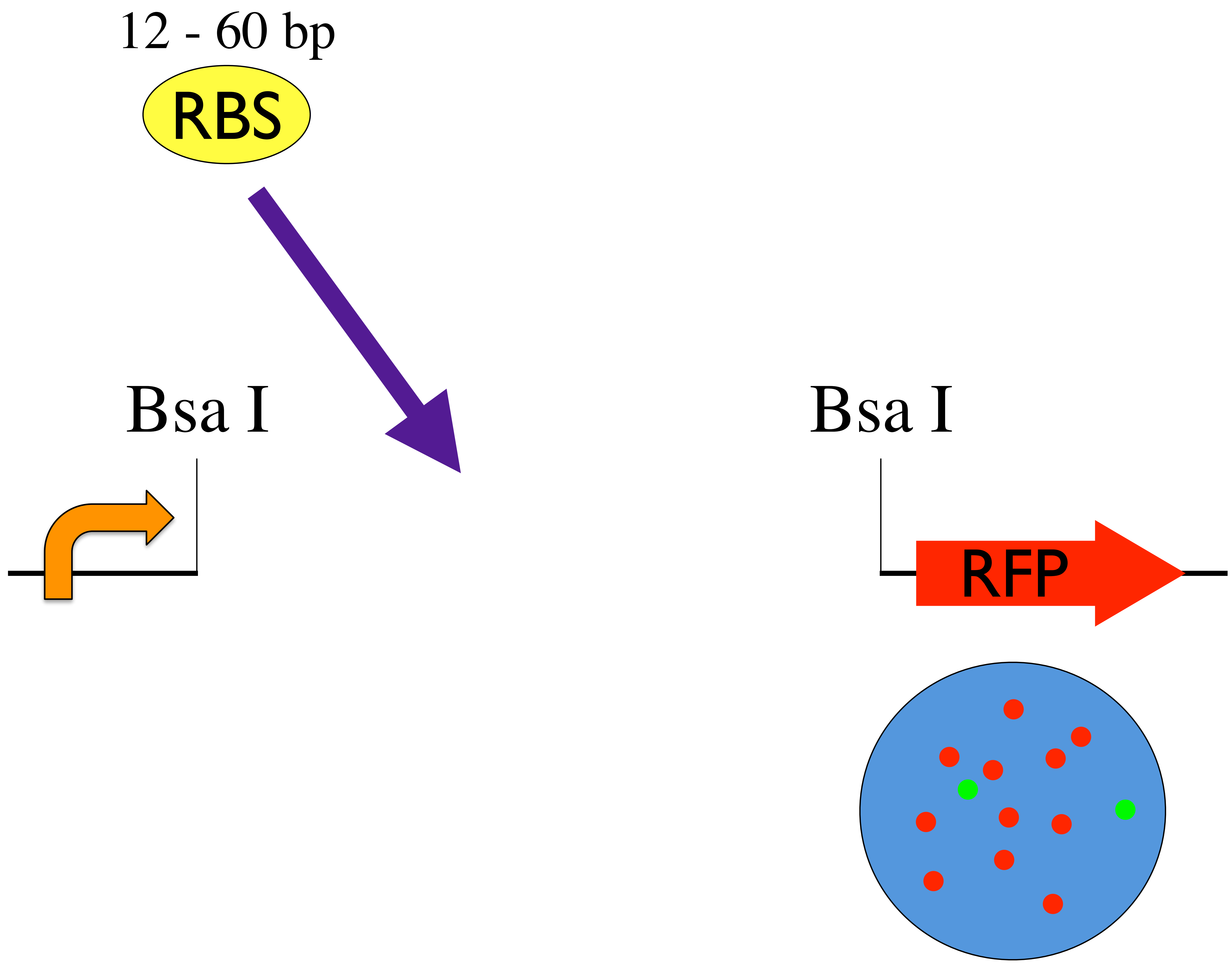
rClone Red (ribosome research)

J119384

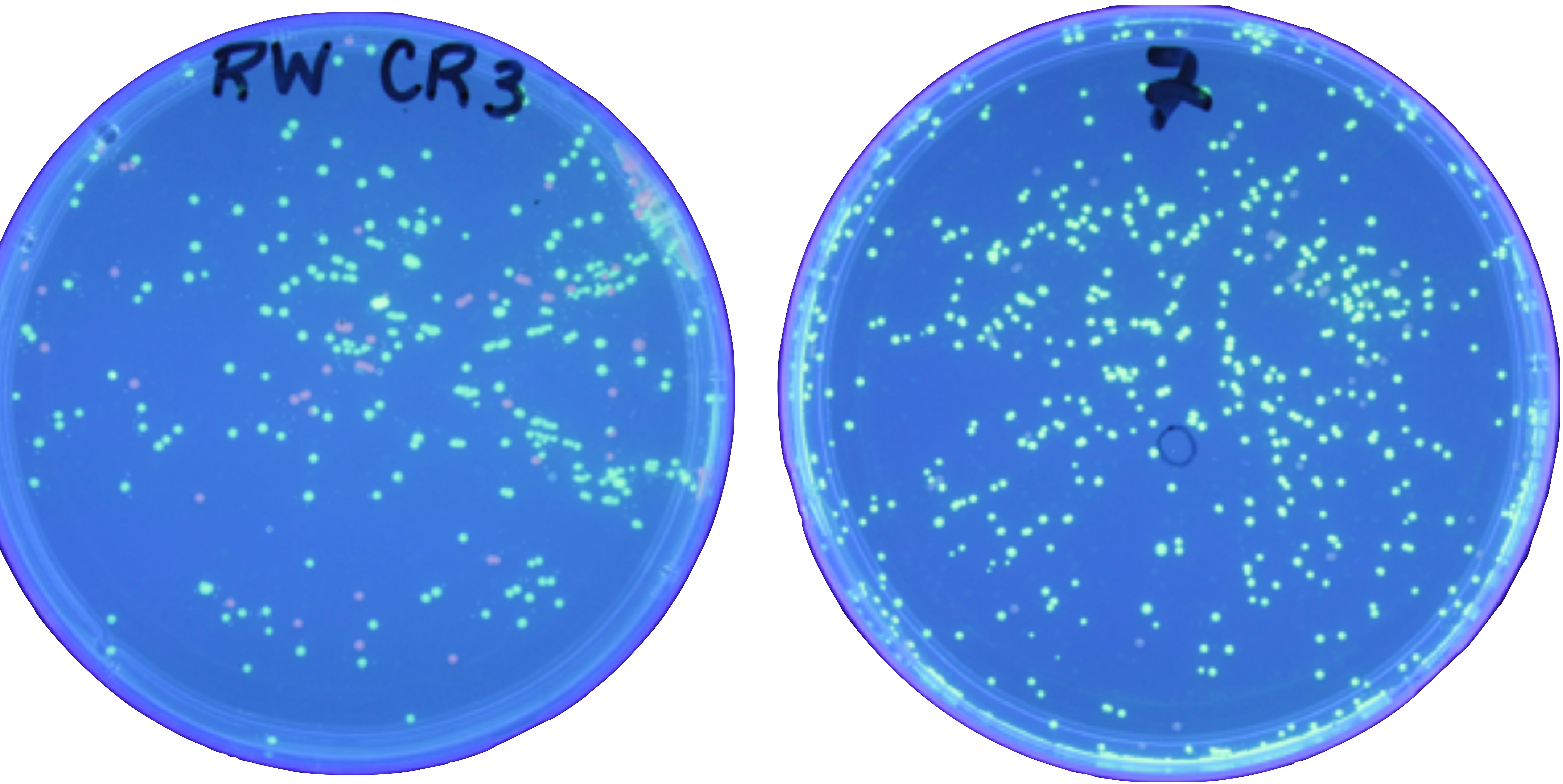


rClone Red (ribosome research)

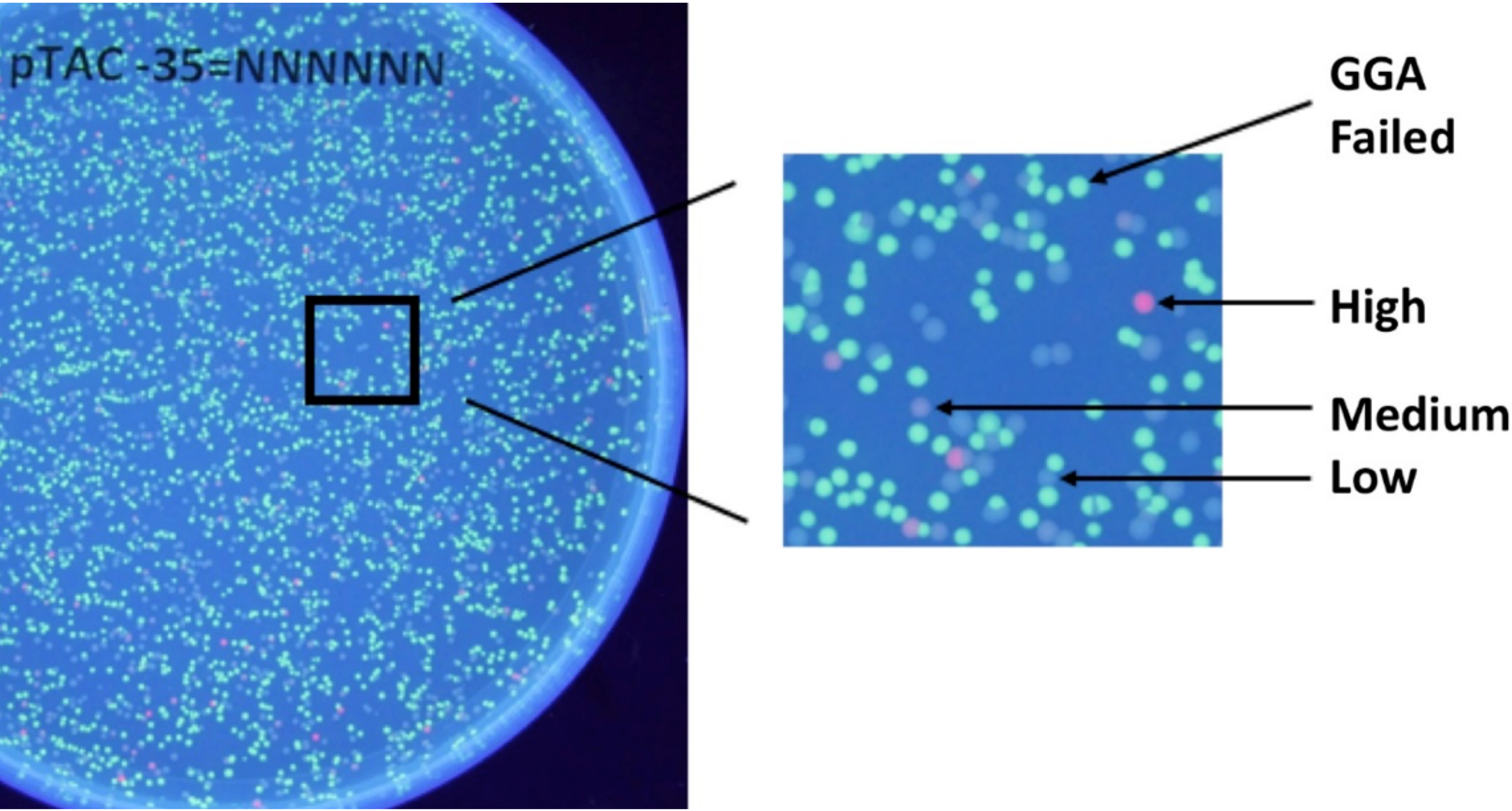
J119384



rClone Red (student-designed RBS)

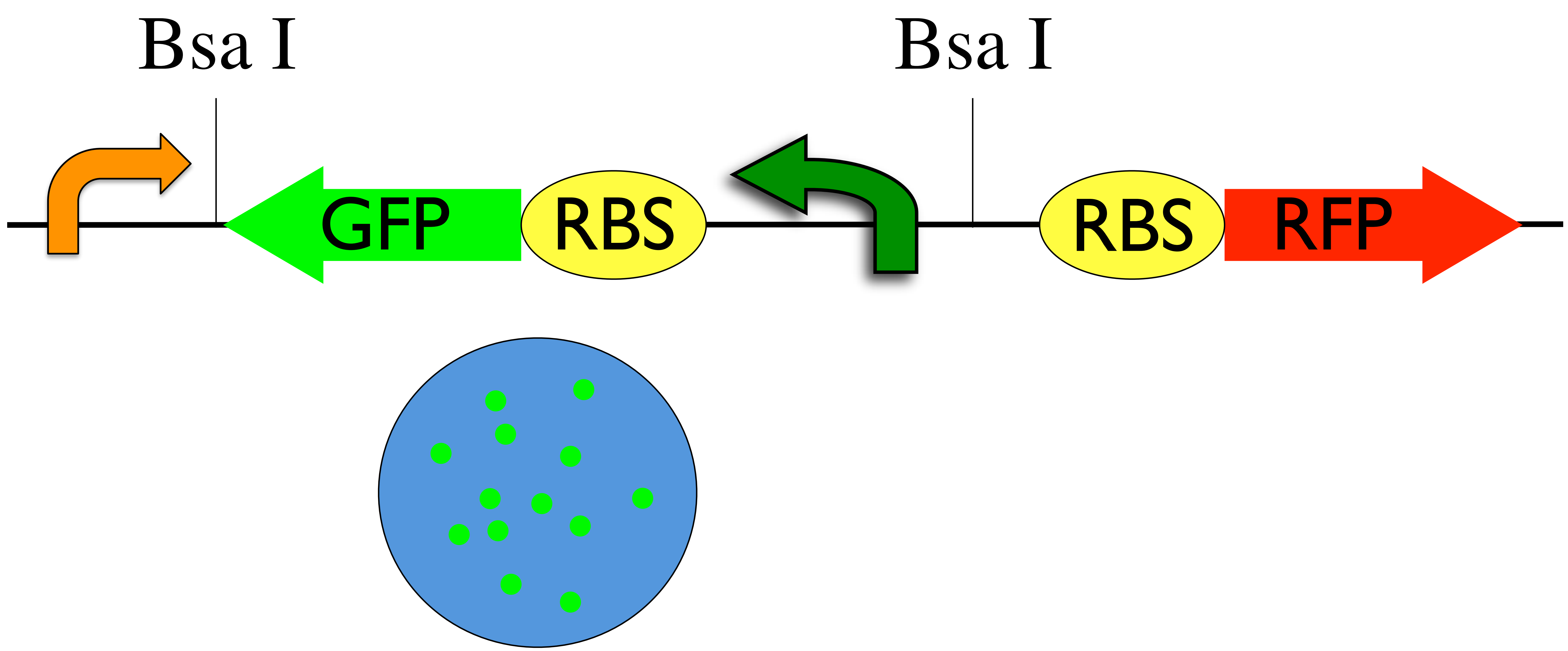


rClone Red (RBS library)



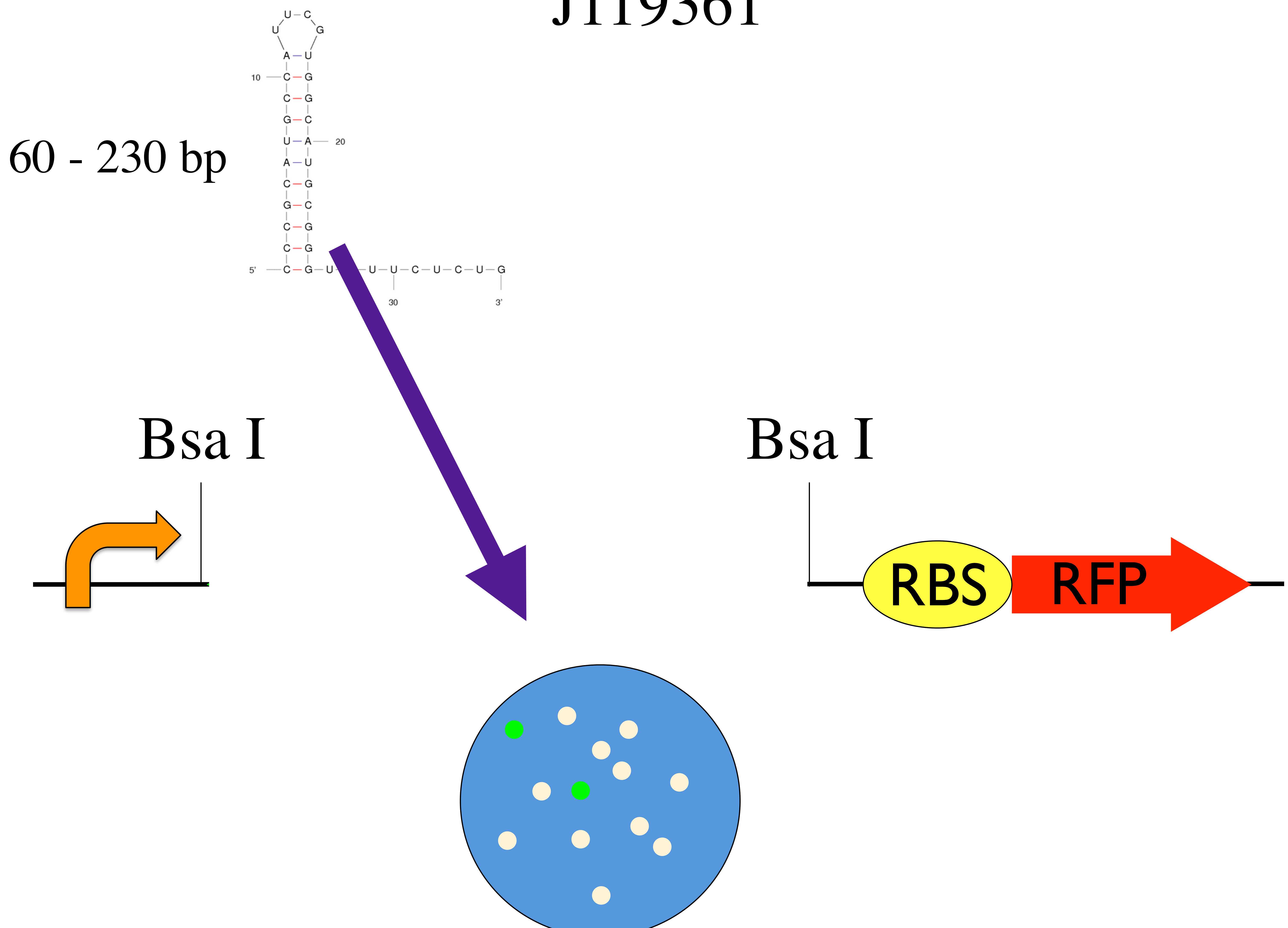
tClone Red (terminator research)

J119361

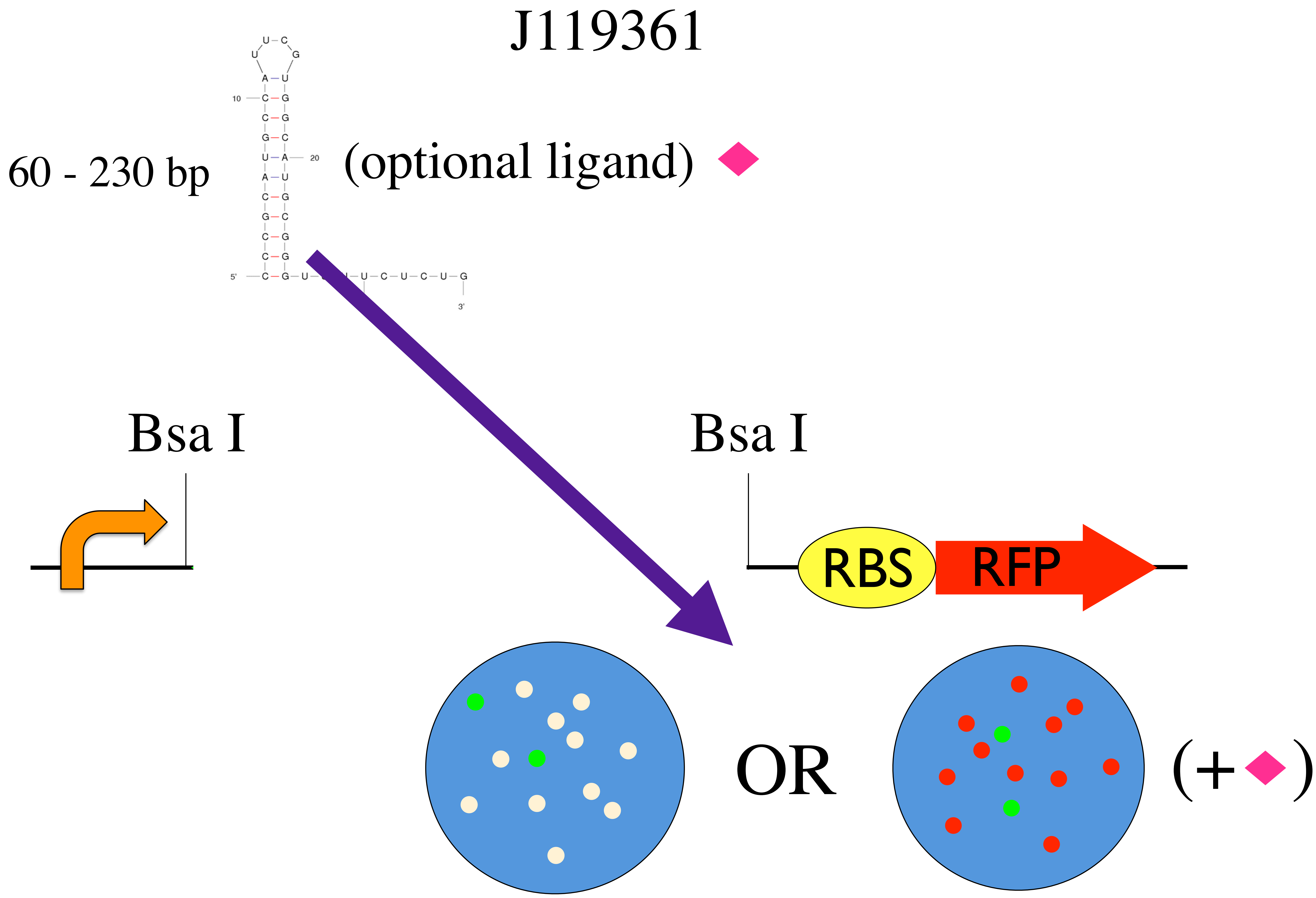


tClone Red (terminator research)

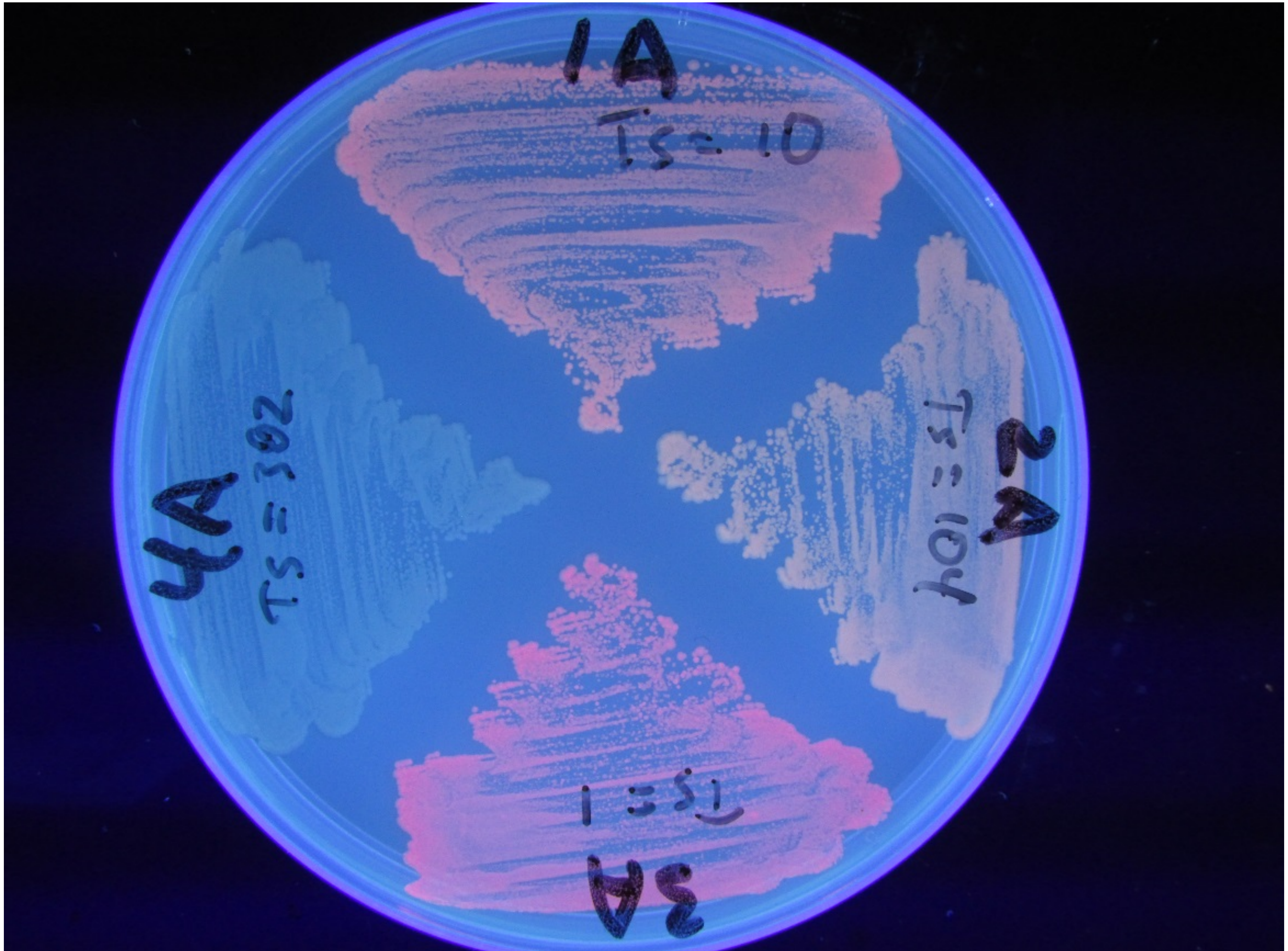
J119361



tClone Red (terminator research)



tClone Red (student-designed terminators)



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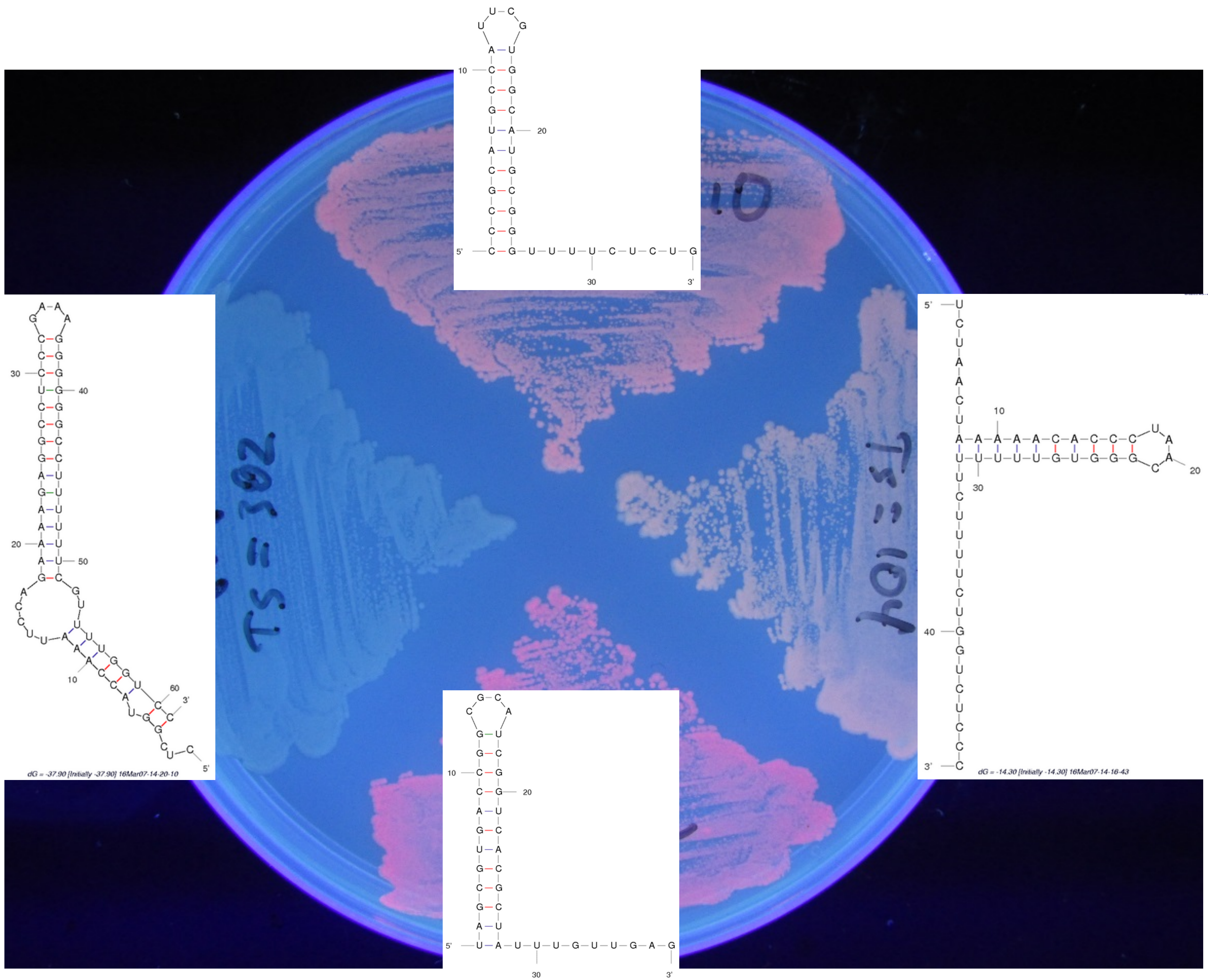
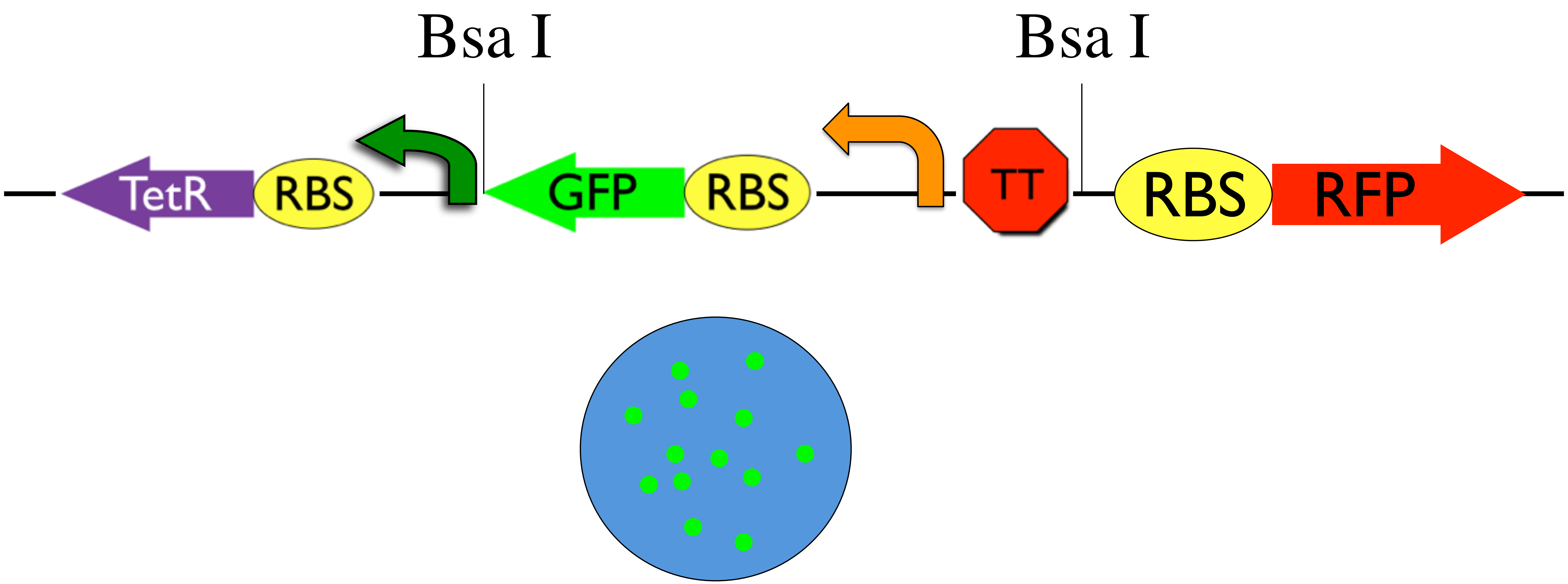


repClone Red

J100205



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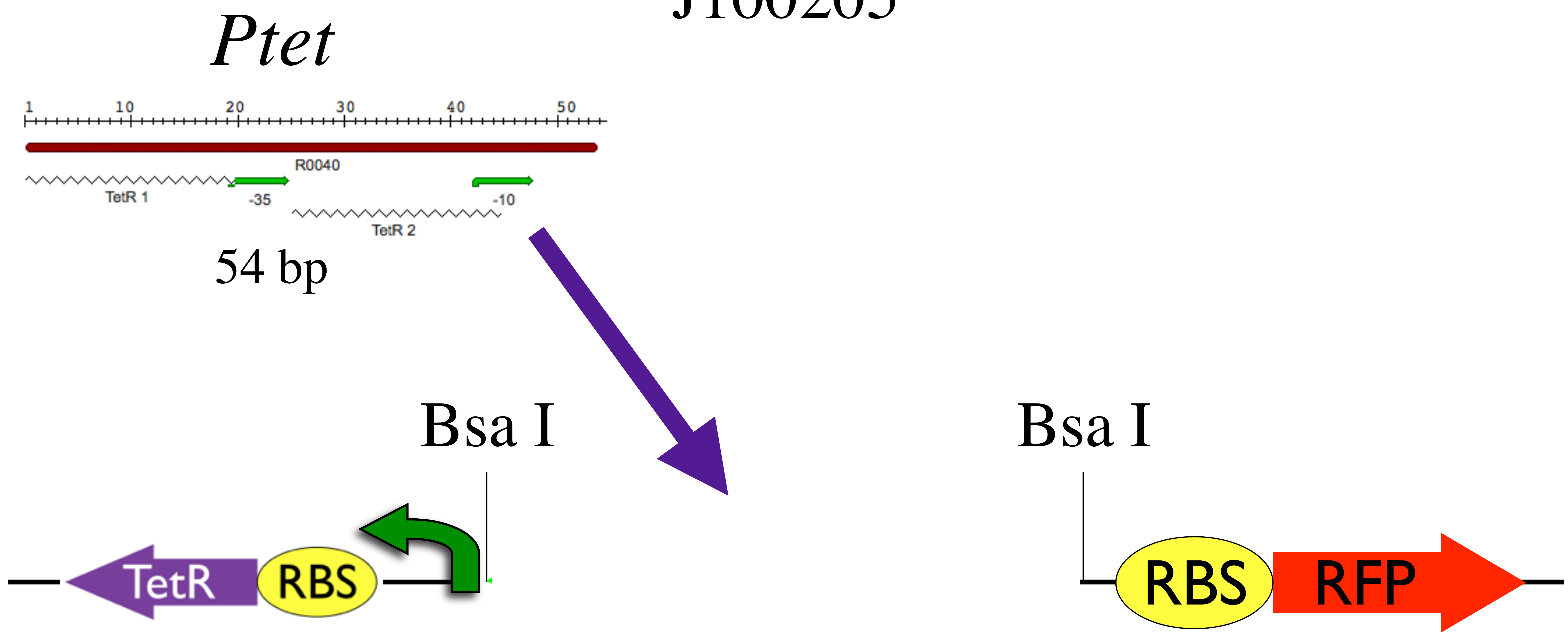

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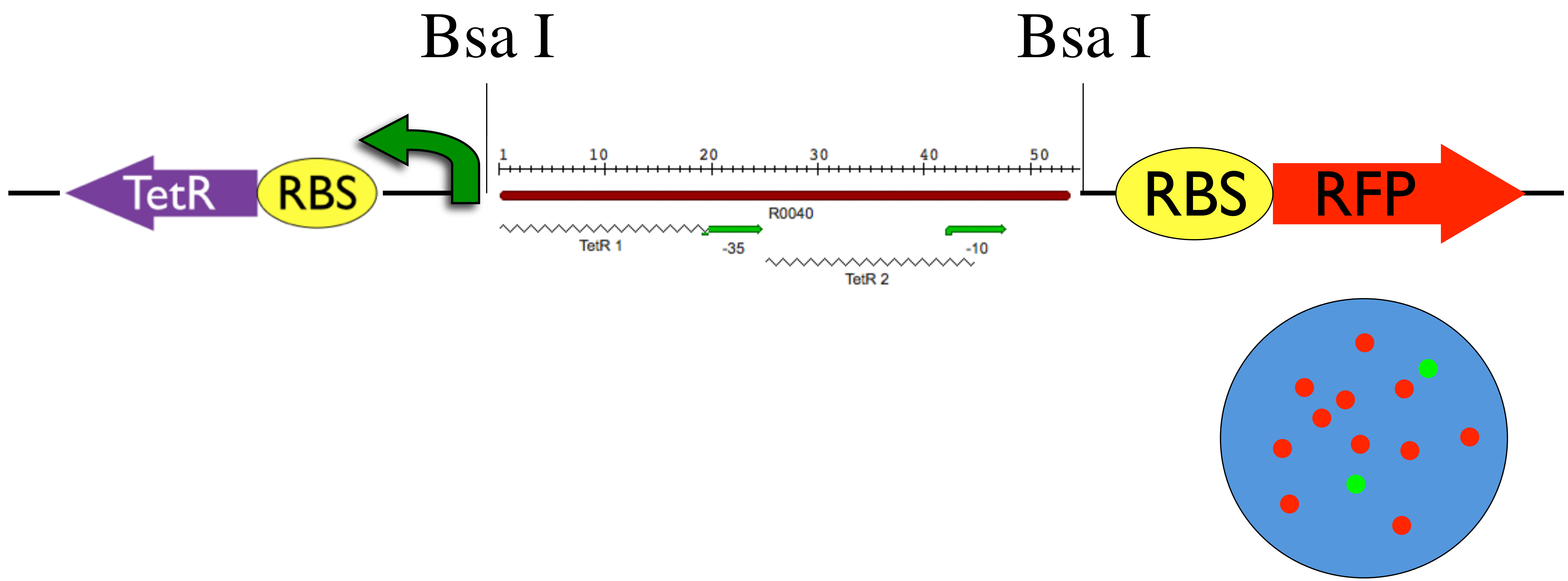

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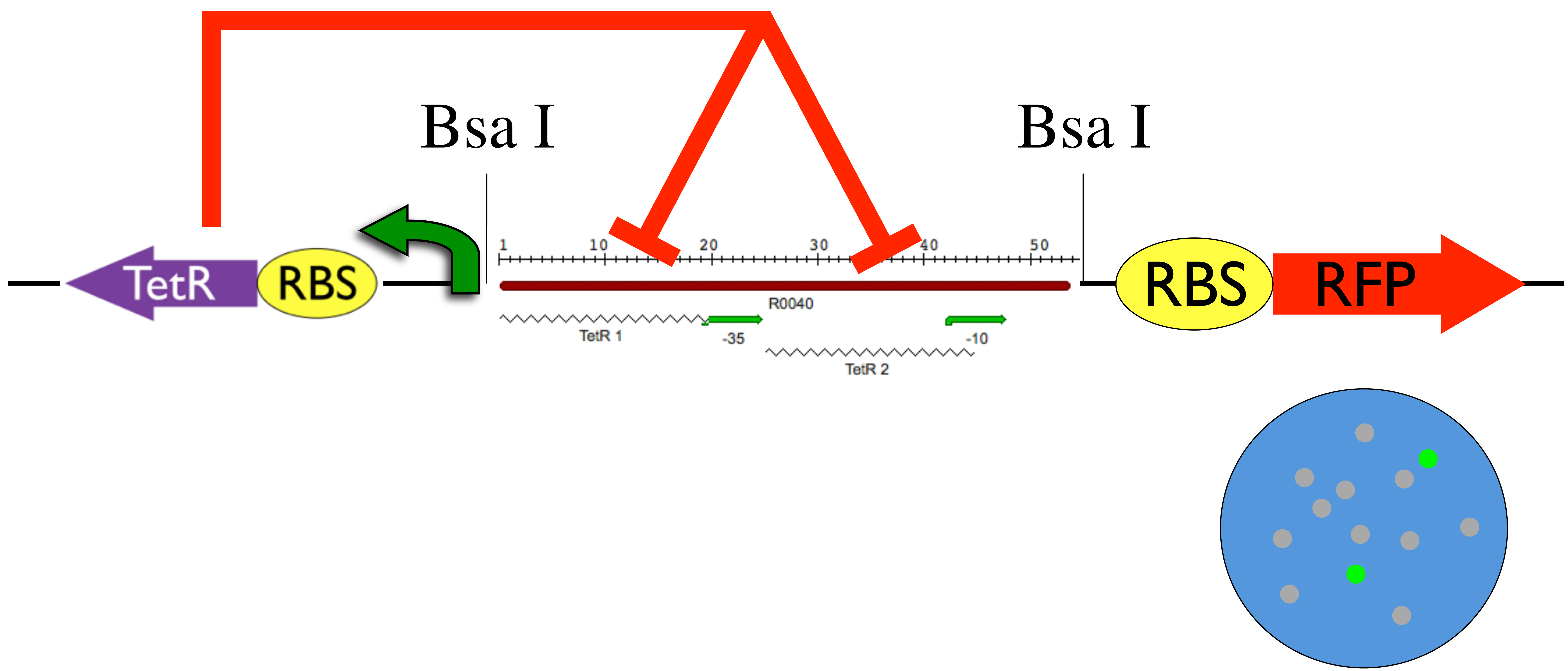

actClone Red

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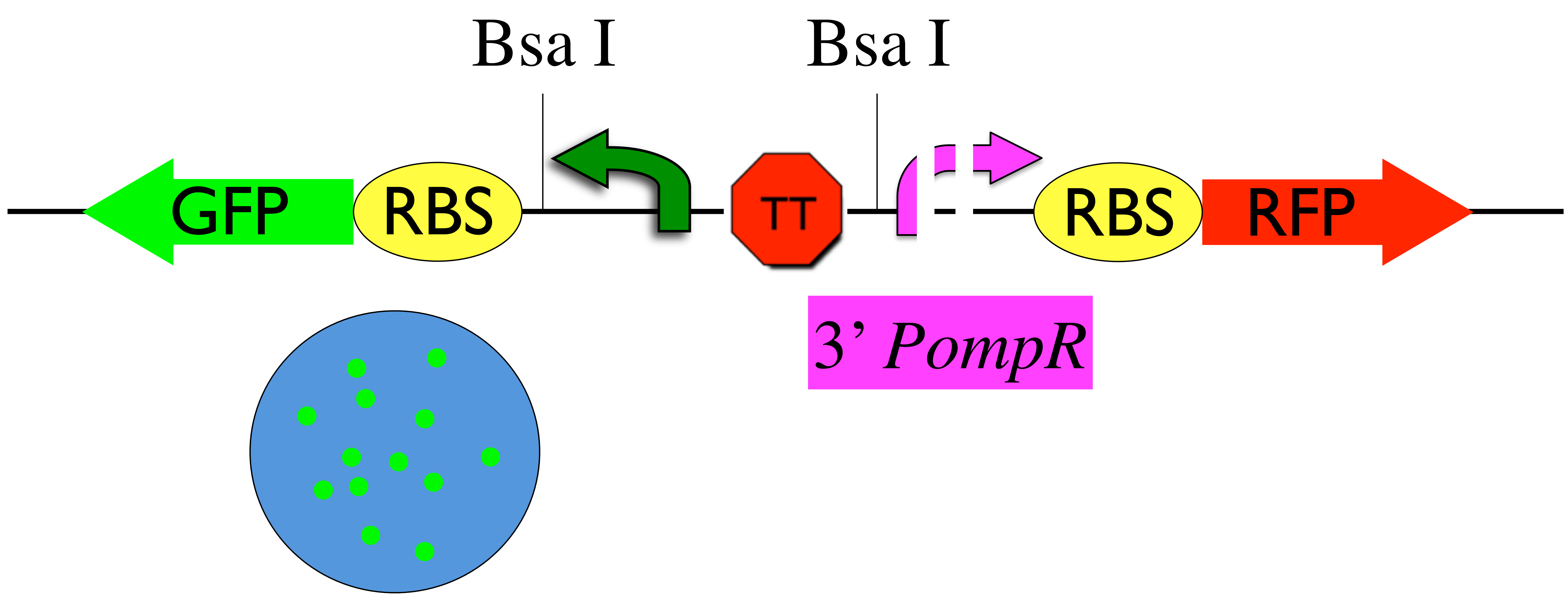

actClone Red

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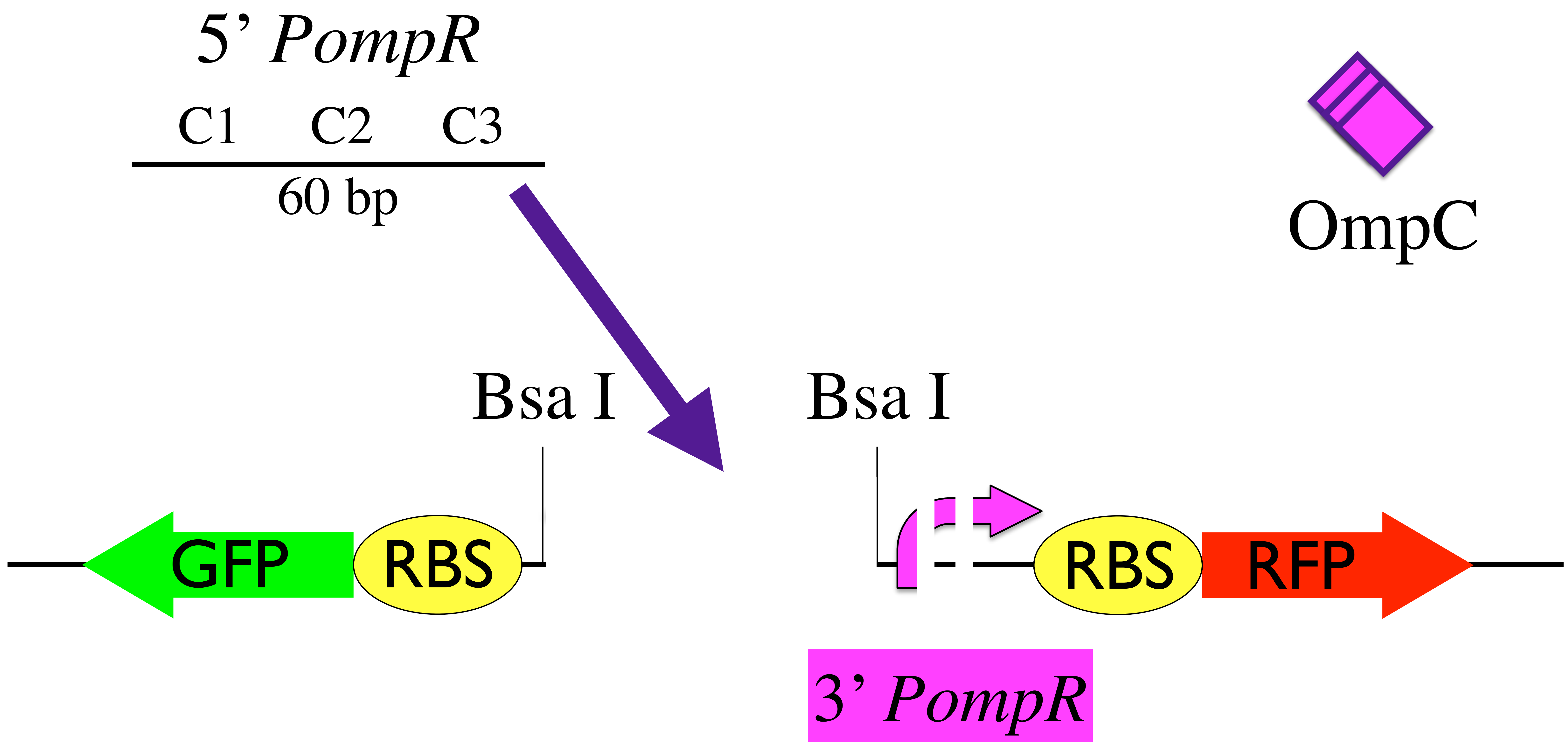

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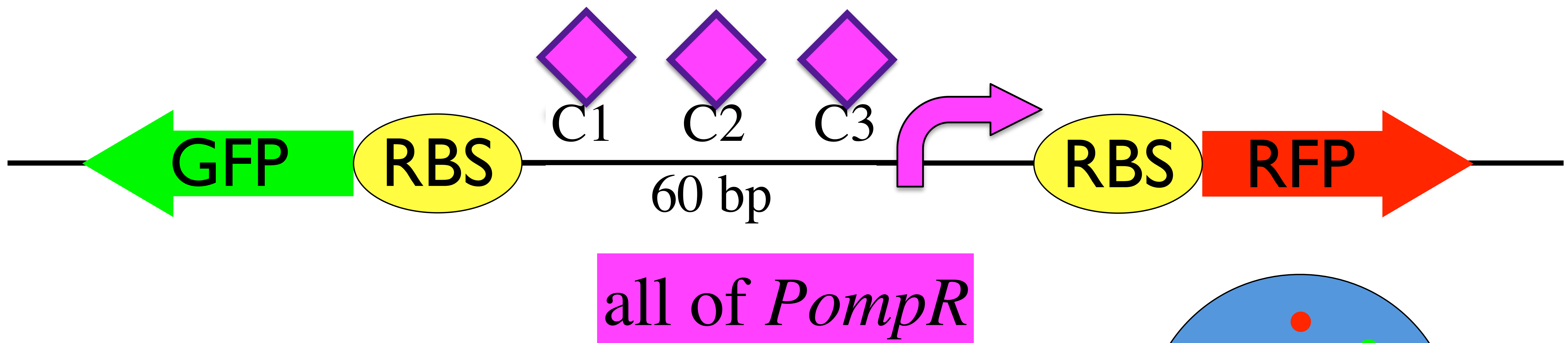
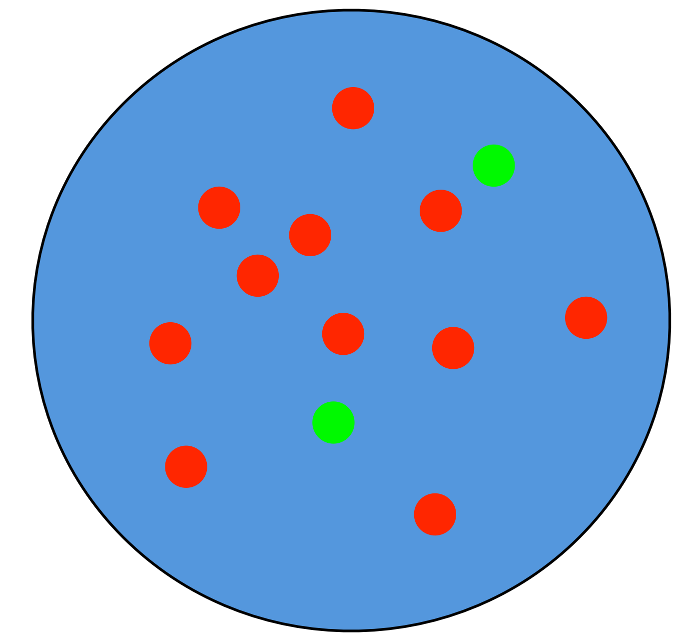
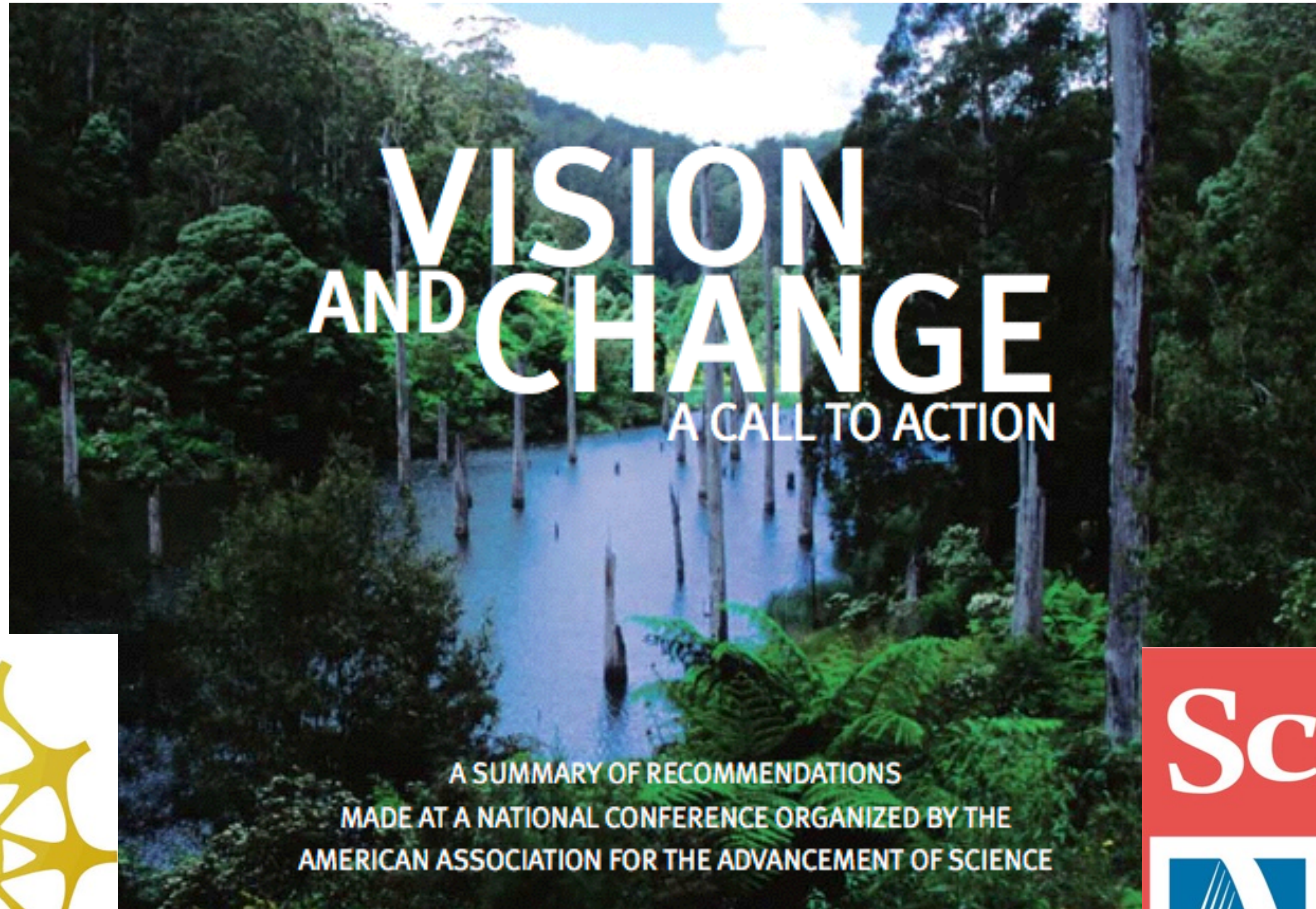




How can we better prepare our undergrads for research?

National Recognition of Need to Change

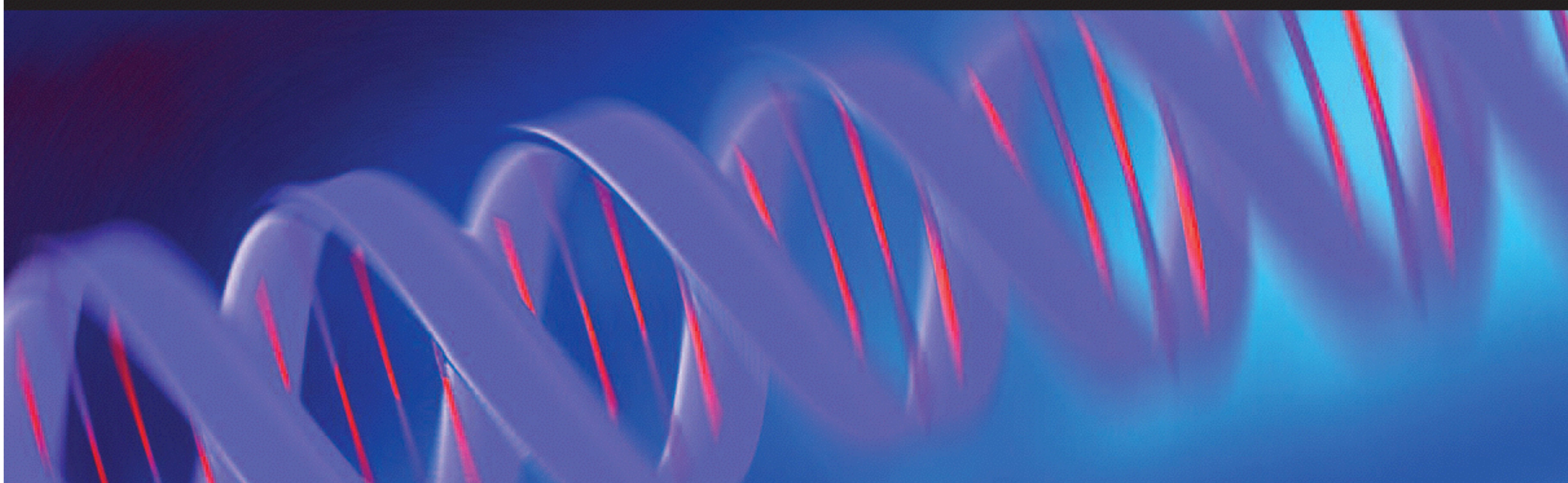


AP Biology Redesign in Third Year

AP® BIOLOGY

Curriculum Framework

2012–2013



GRE General Test

Verbal Reasoning: measures your ability to understand what you read and how you apply your reasoning skills.

Quantitative Reasoning: measures your ability to

- understand quantitative information
- interpret and analyze quantitative information
- solve problems using mathematical models
- apply basic mathematical skills and elementary mathematical concepts of arithmetic, algebra, geometry and data interpretation
- includes real-life scenarios

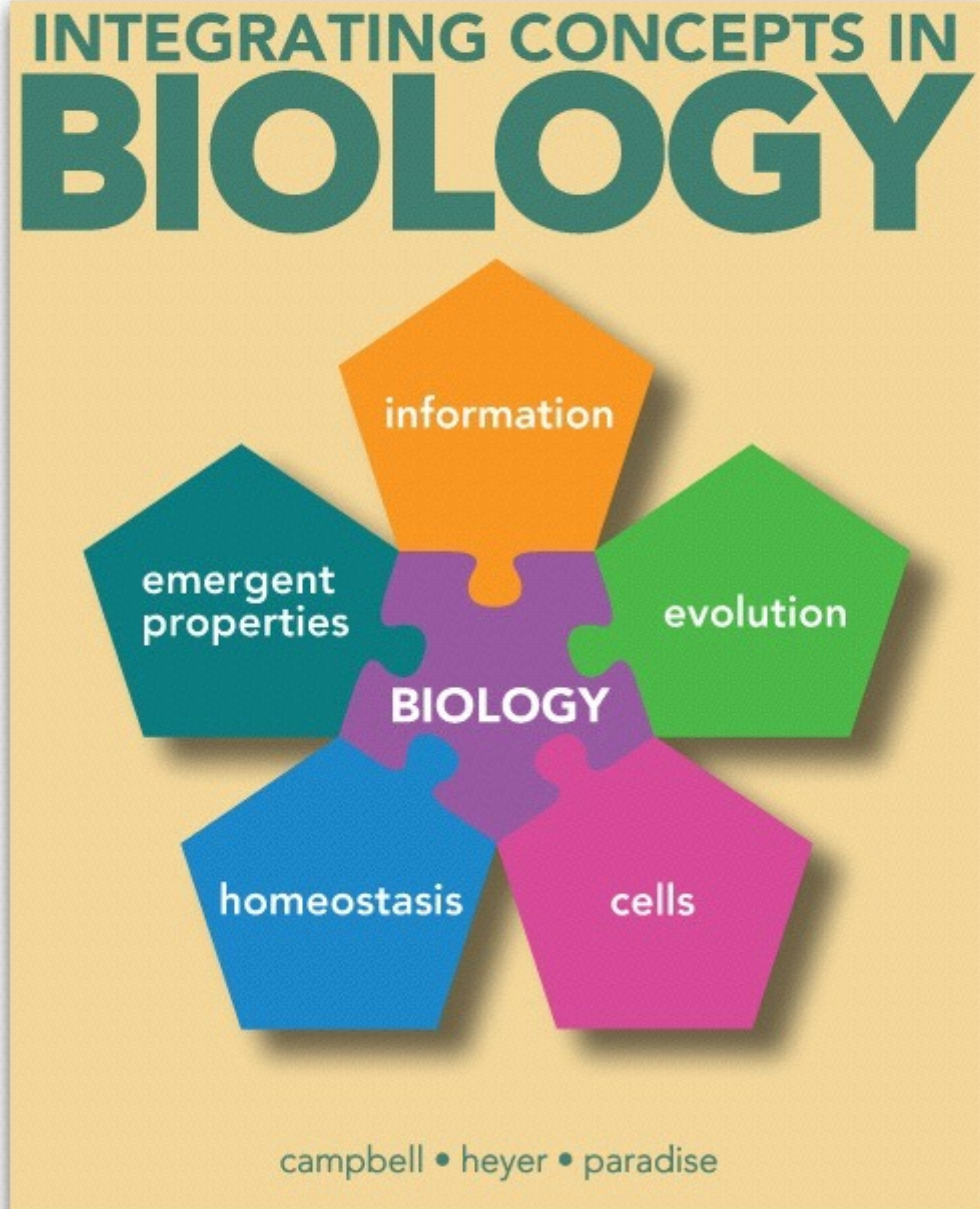
Analytical Writing: provide focused responses to prompts so you can demonstrate your ability to directly respond.

MCAT Redesigned Test

Critical Analysis and Reasoning Skills: analyze, evaluate, and apply information provided in passages

Natural Sciences: combine knowledge of natural science concepts with their scientific inquiry and <u>reasoning skills to solve problems</u> that demonstrate their readiness for medical school.

Psychological, Social, and Biological Foundations of Behavior



full disclosure

ICB is a commercial product

www.bio.davidson.edu/icb

Core Concepts = Big Ideas

Vision & Change
Evolution
Structure and Function
Information
Energy and Matter
Systems Biology

AP Biology
Evolution
Information
Homeostasis
Emergent Properties

ICB
Evolution
Cells
Information
Homeostasis
Emergent Properties

V&C Core Competencies

- Apply the process of science
- Use quantitative reasoning
- Use modeling and simulations
- Integrate different disciplines
- Communicate & collaborate
- Connect science & society

V&C Core Competencies (*ICB*)

- Apply the process of science (experimental design)
- Use quantitative reasoning (interpret raw data)
- Use modeling and simulations (work with models)
- Integrate different disciplines (chemistry, math, some physics)
- Communicate & collaborate (small group discussions, lab)
- Connect science & society (ELSI boxes)

What's Wrong with Biology Education Now?

- **Vocabulary is over-emphasized** (800-1000 vs 1400)
- **Experimental approaches are minimized**
- **Math is rarely used**
- **Memorization is rewarded**
- **Critical thinking is discouraged**
- **Information is irrelevant to students**

Present information and data…

… in the context of the big picture.

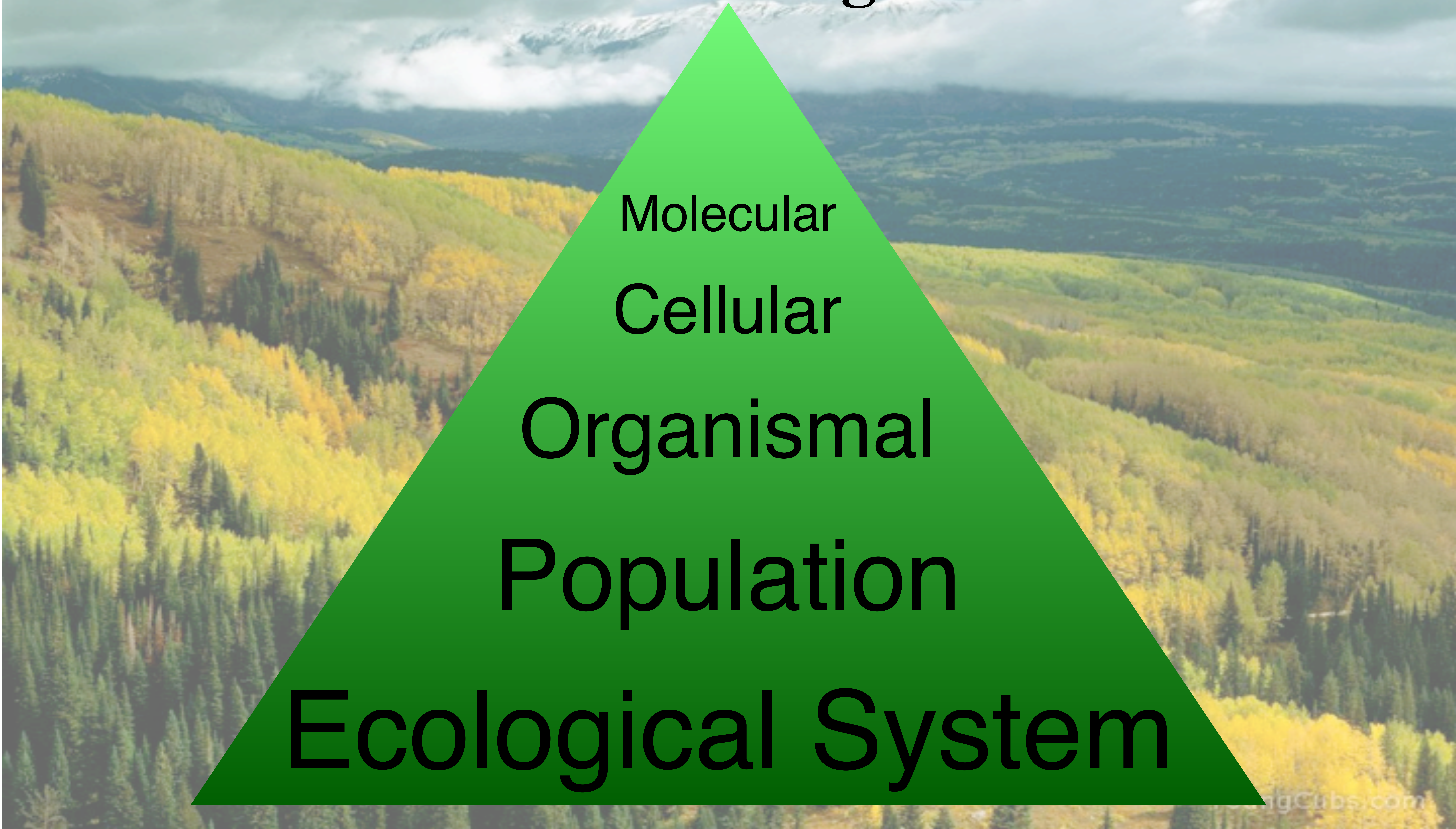
Start with the literature…

Artificial Divide within Biology

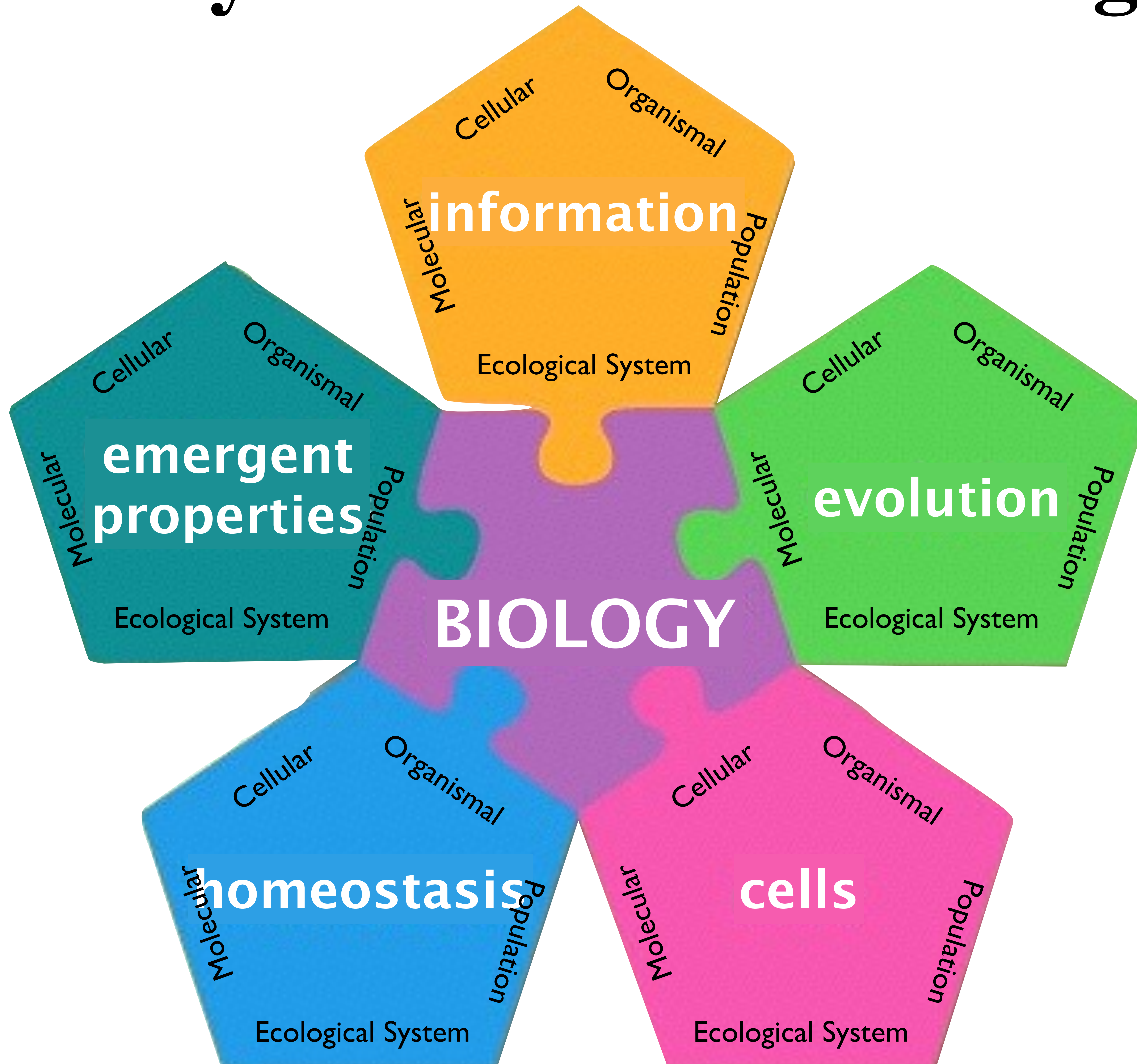
Small Biology

Big Biology

Five Levels of Organization

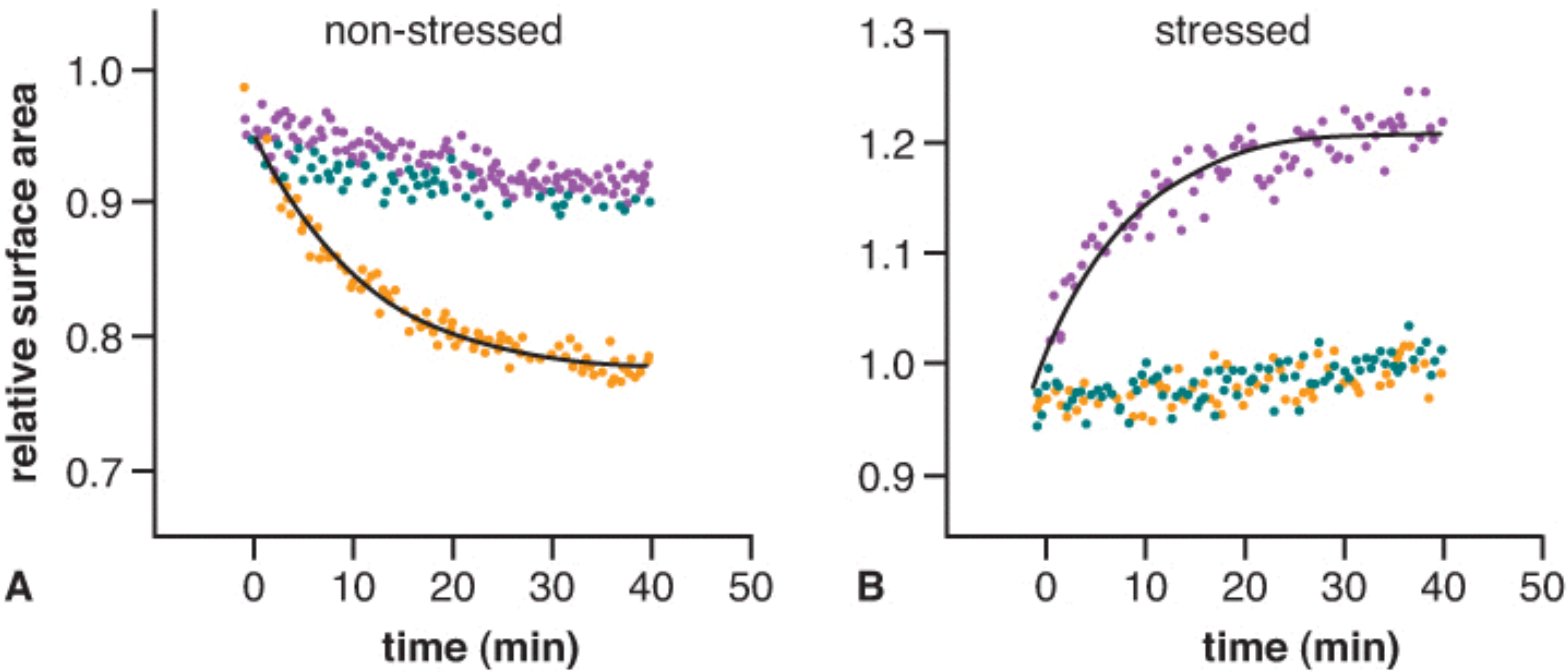


Five by Five Matrix of Biology

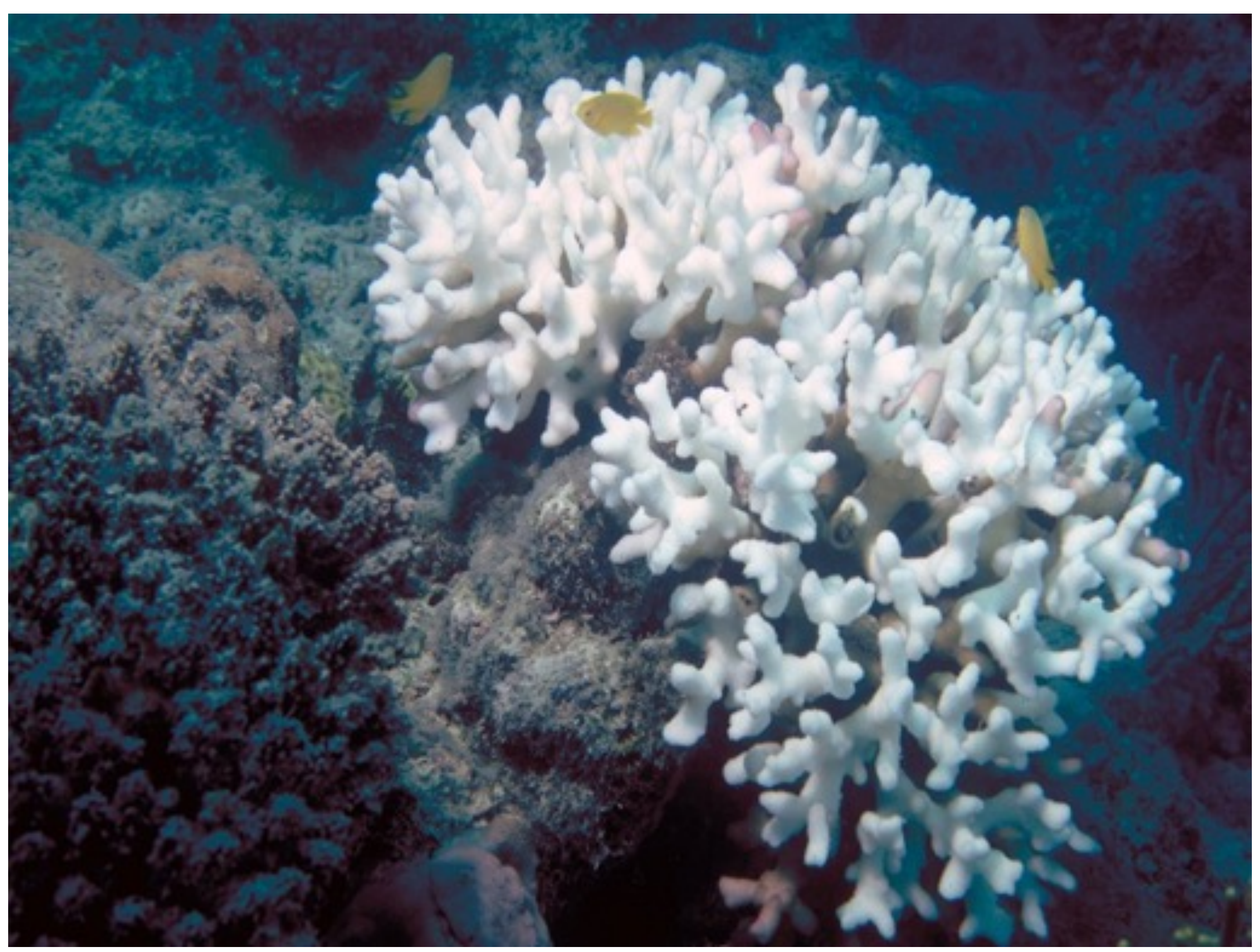


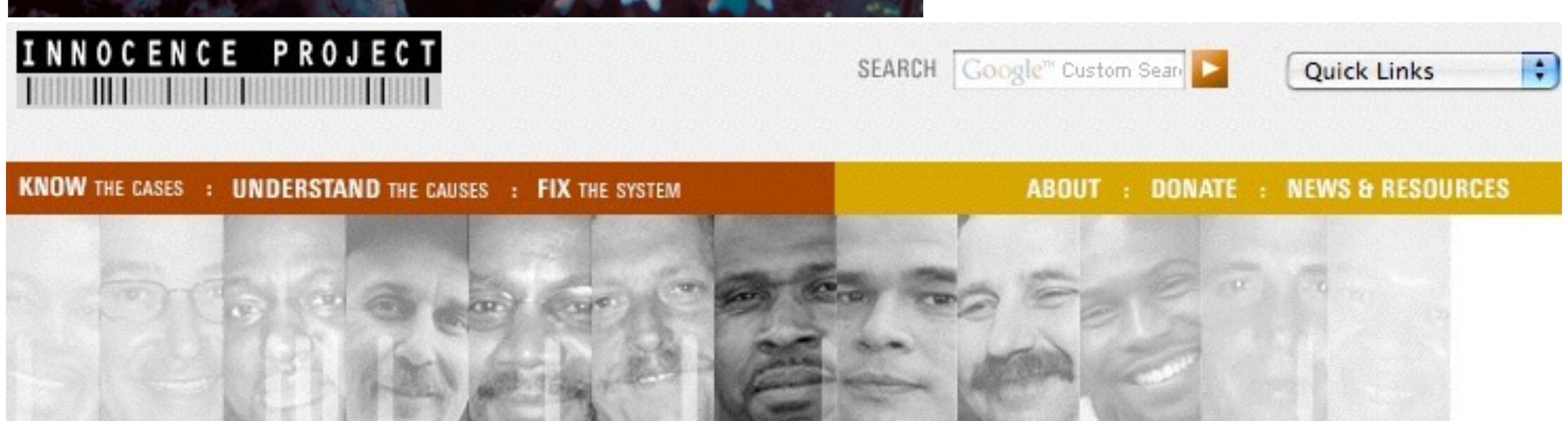
BioMath Exploration 4.2 (BME)

How fast is the vesicle size changing?



Ethical, Legal and Social Implications (ELSI)





Are religion and evolution compatible?

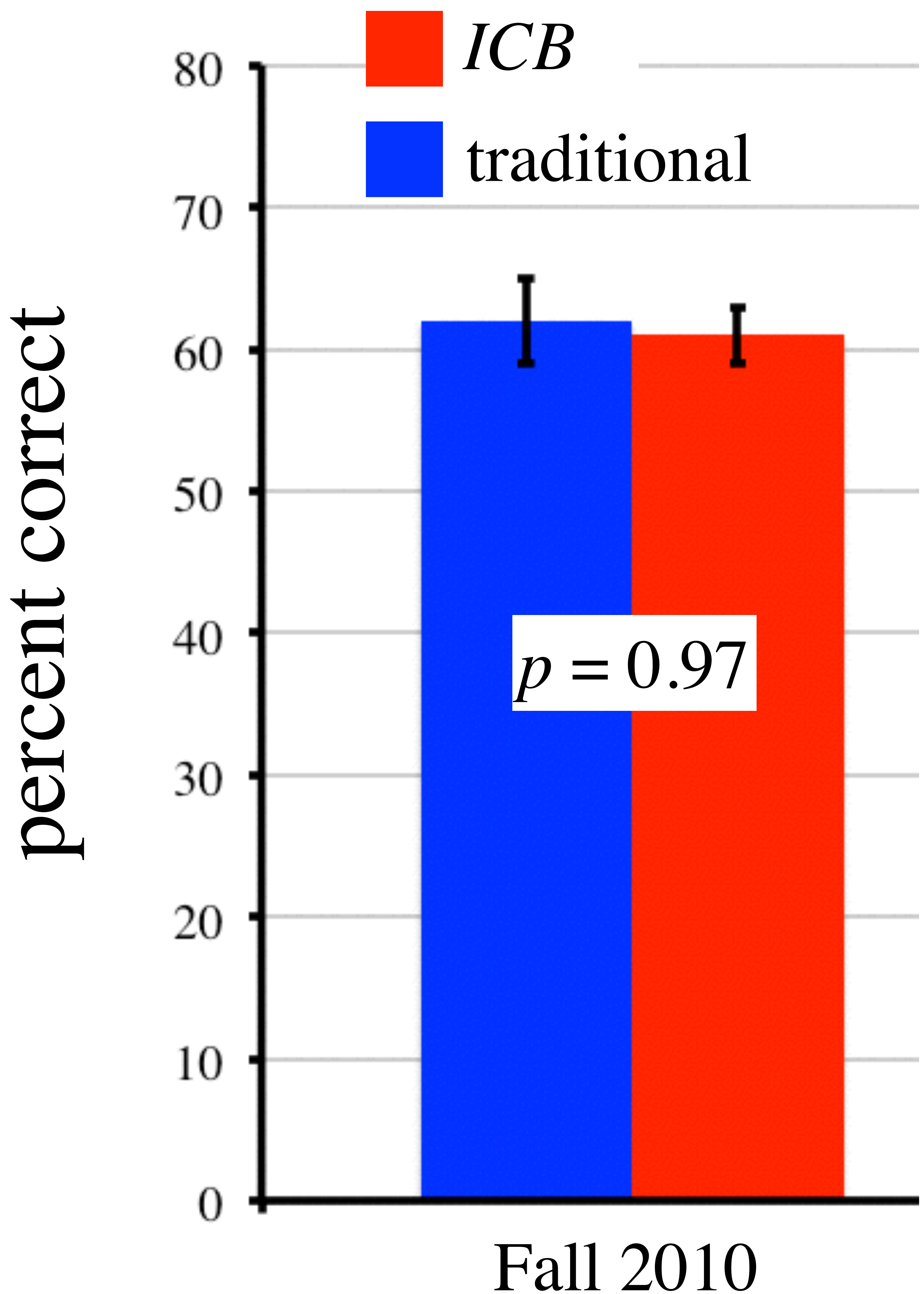
Is science possible if you are uncertain about what is true?

Does basic biology have any impact on the real world?

Who owns your DNA?

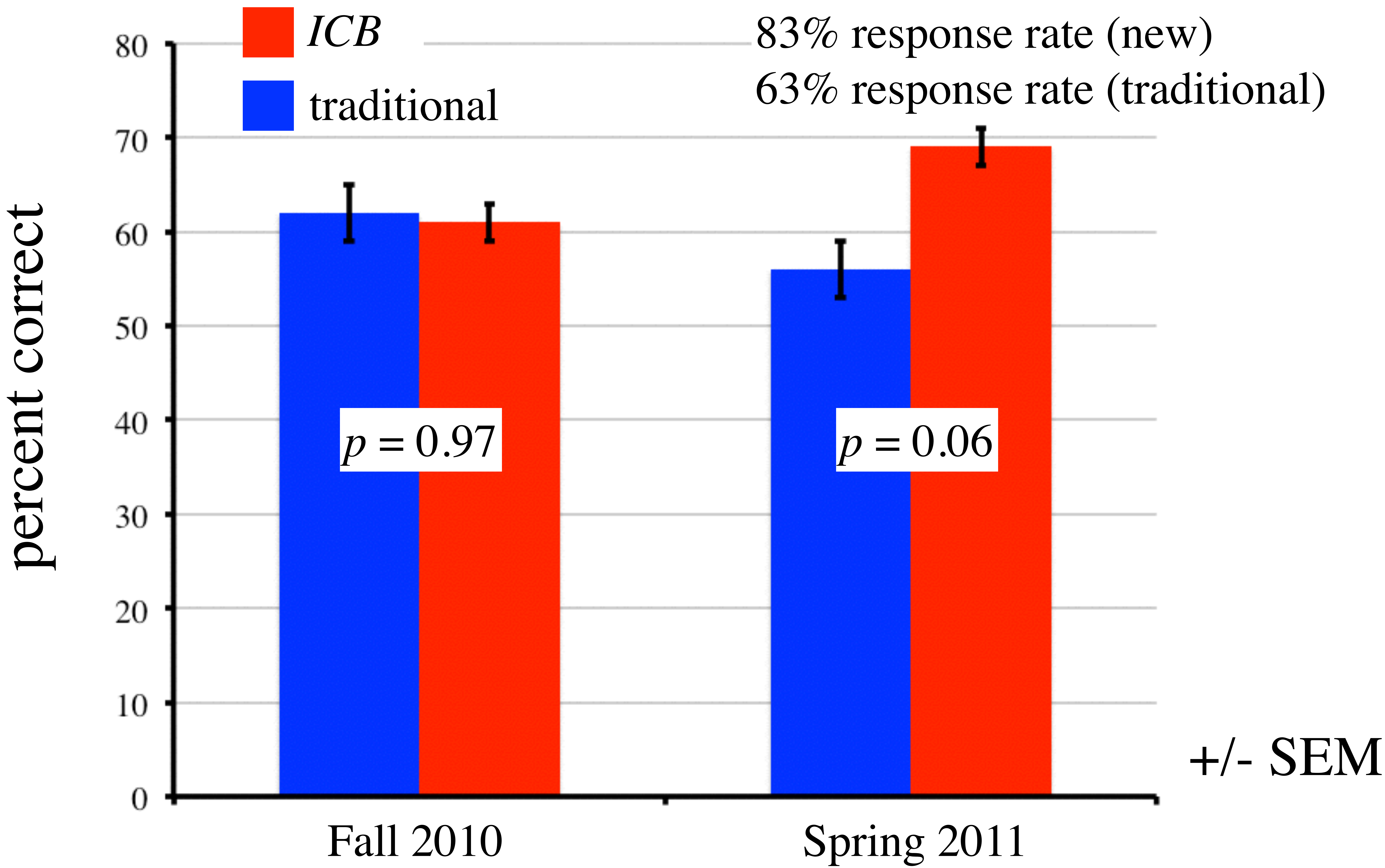
Did *ICB* students “learn less” content?

Core Concepts Assessment



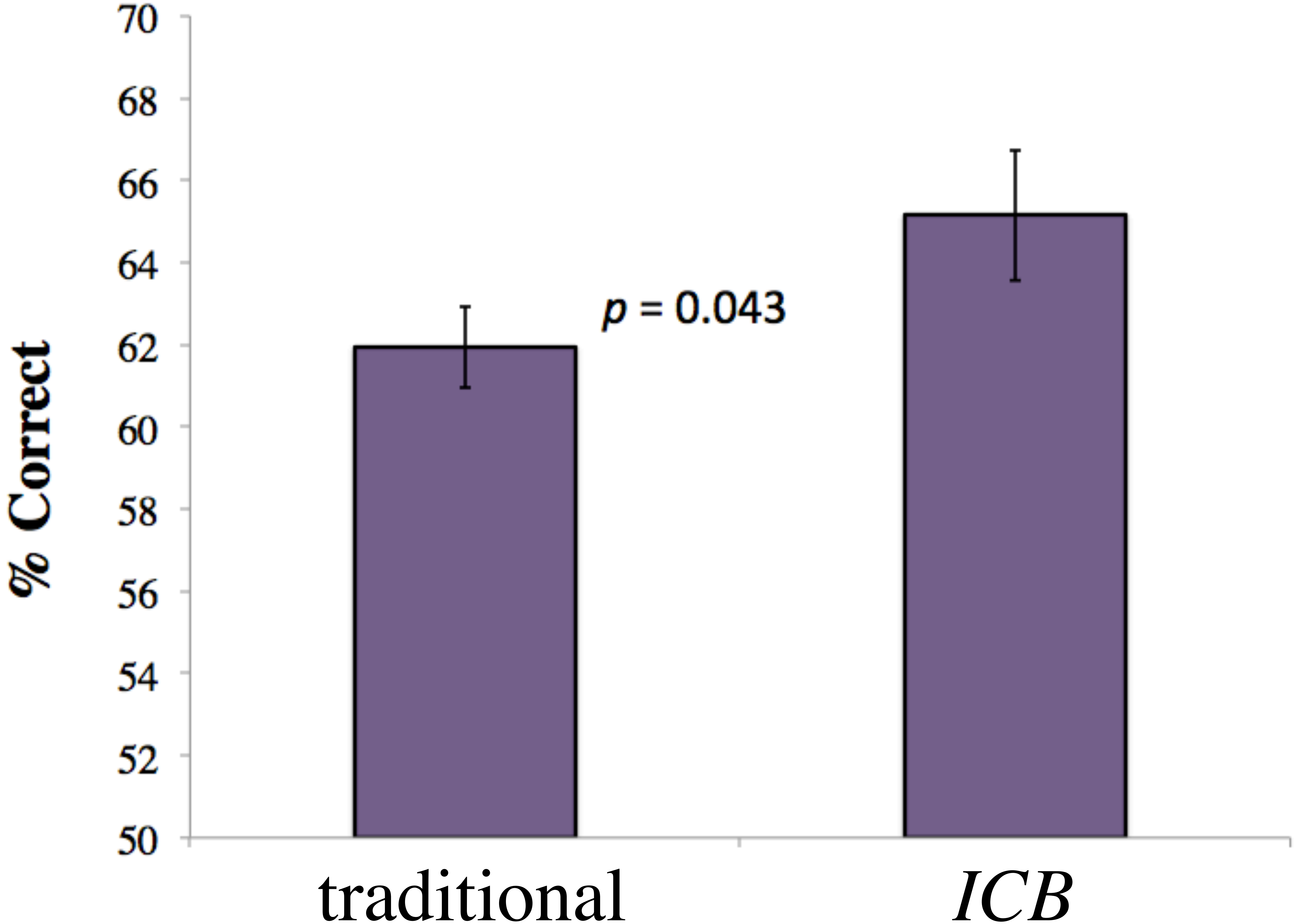
+/- SEM

Core Concepts Assessment

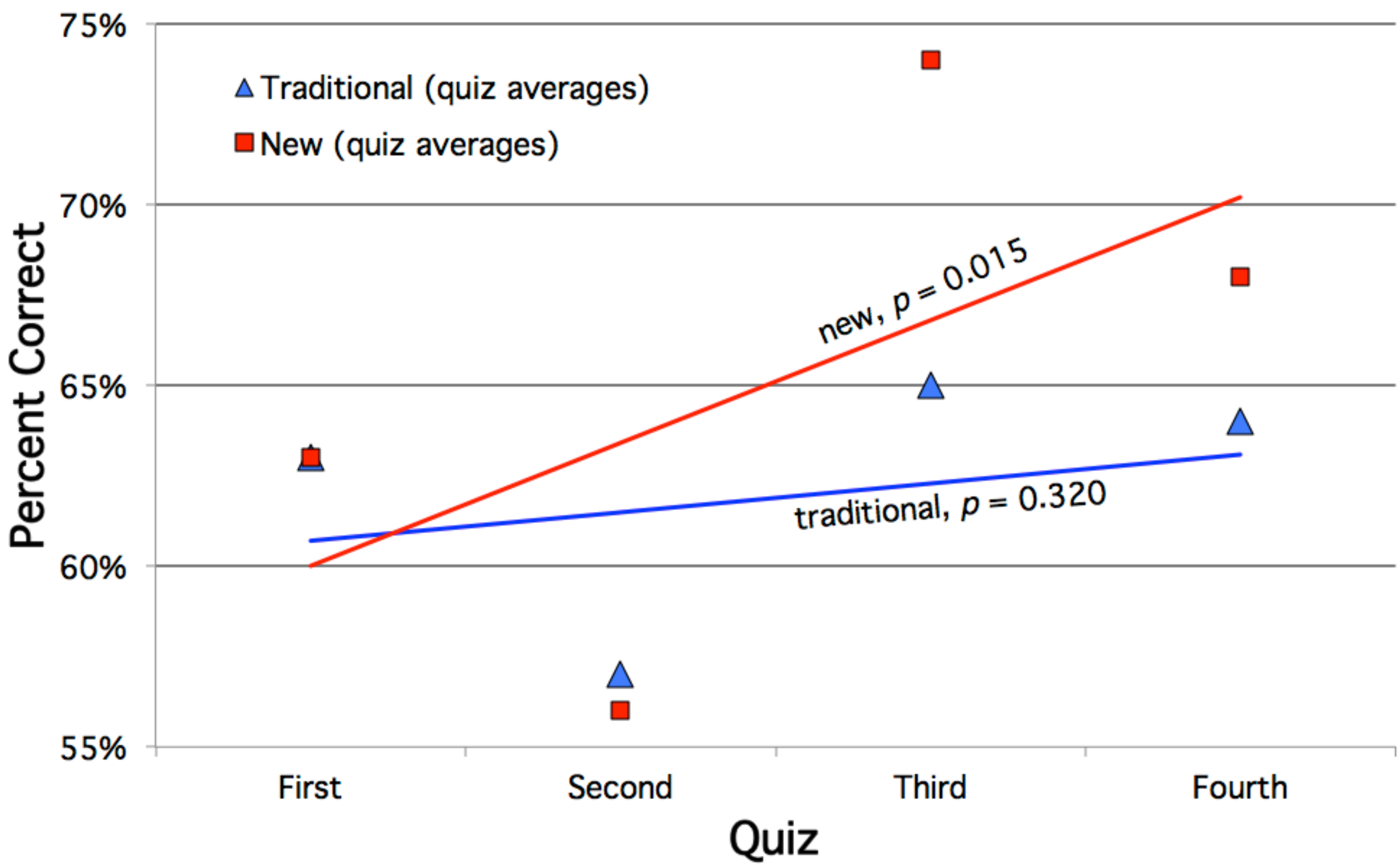


Do *ICB* students analyze data better?

Core Competency Assessment



Core Competency Assessment



Do *ICB* students see biology differently?

1-5 scale 5 = extremely accurate	Average at Start Fall	
	ICB	**Traditional**
biology is definitions & processes	2.86	2.61
big questions of biology already answered	1.71	1.50
big/small division of biology describes nature	3.15	3.02
1-5 scale 5 = extremely important		
memorization	3.96	3.64

* p<0.05, ** p<0.01, *** p<0.001, ^ p= 0.06

no

Do *ICB* students see biology differently?

1-5 scale 5 = extremely accurate	Average at Start Fall		Δ in Average End of Fall	
	ICB	Traditional	ICB	Traditional
biology is definitions & processes	2.86	2.61	-0.58*** yes!	+0.50
big questions of biology already answered	1.71	1.50	-0.32* yes!	+0.22
big/small division of biology describes nature	3.15	3.02	-1.08*** yes!	-0.06
1-5 scale 5 = extremely important			yes!	
memorization	3.96	3.64	-1.48***	-0.08

* p<0.05, ** p<0.01, *** p<0.001, ^ p= 0.06

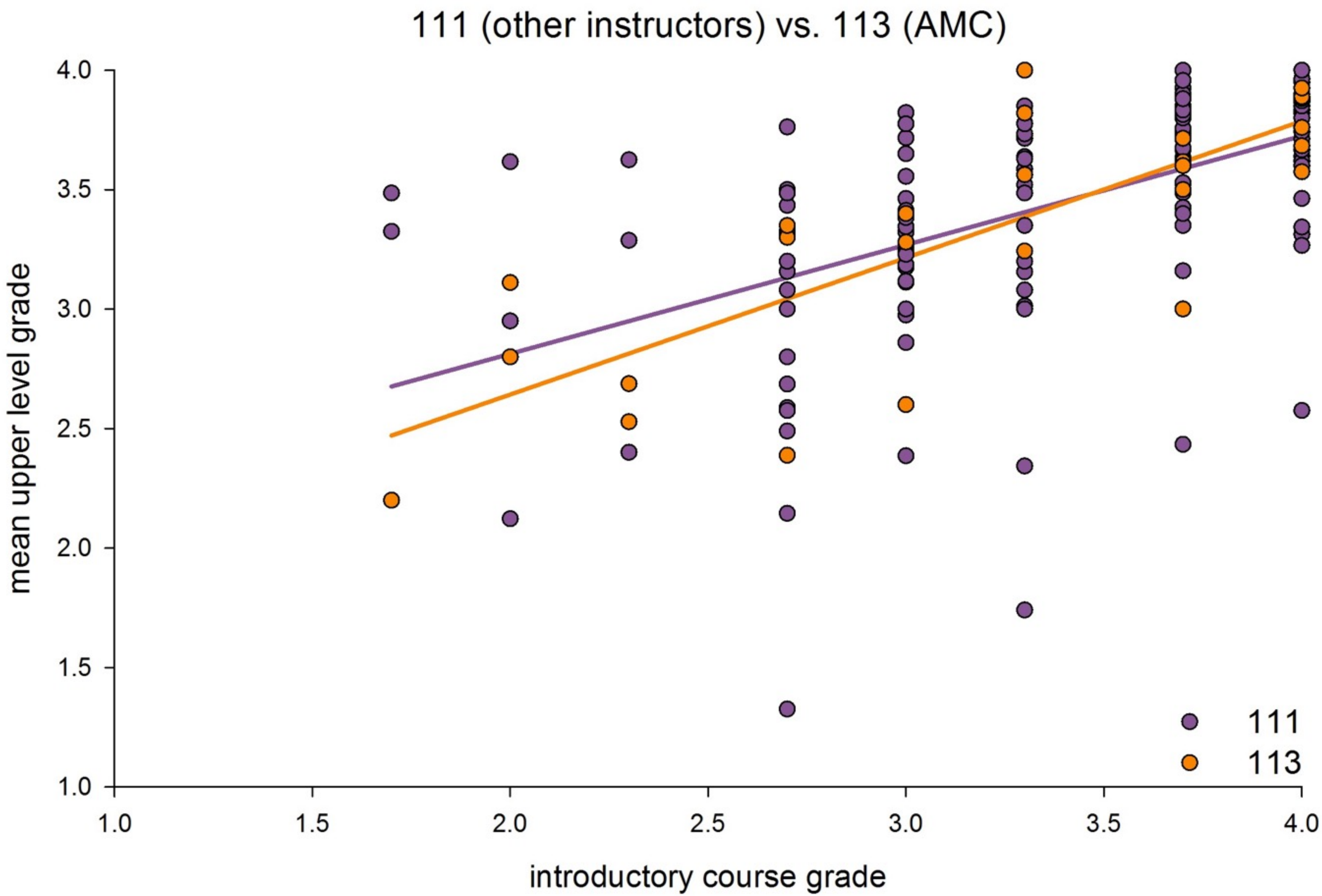
Do *ICB* students see biology differently?

1-5 scale 5 = extremely accurate	Average at Start Fall		Δ in Average End of Fall		Δ in Average End of Spring	
	ICB	Traditional	ICB	Traditional	ICB	Traditional
biology is definitions & processes	2.86	2.61	-0.58***	+0.50	-0.46*** yes!	+0.45
big questions of biology already answered	1.71	1.50	-0.32*	+0.22	-0.33^ yes?	0.00
big/small division of biology describes nature	3.15	3.02	-1.08***	-0.06	-0.75** yes!	-0.10
1-5 scale 5 = extremely important					yes!	
memorization	3.96	3.64	-1.48***	-0.08	-1.27***	+0.23

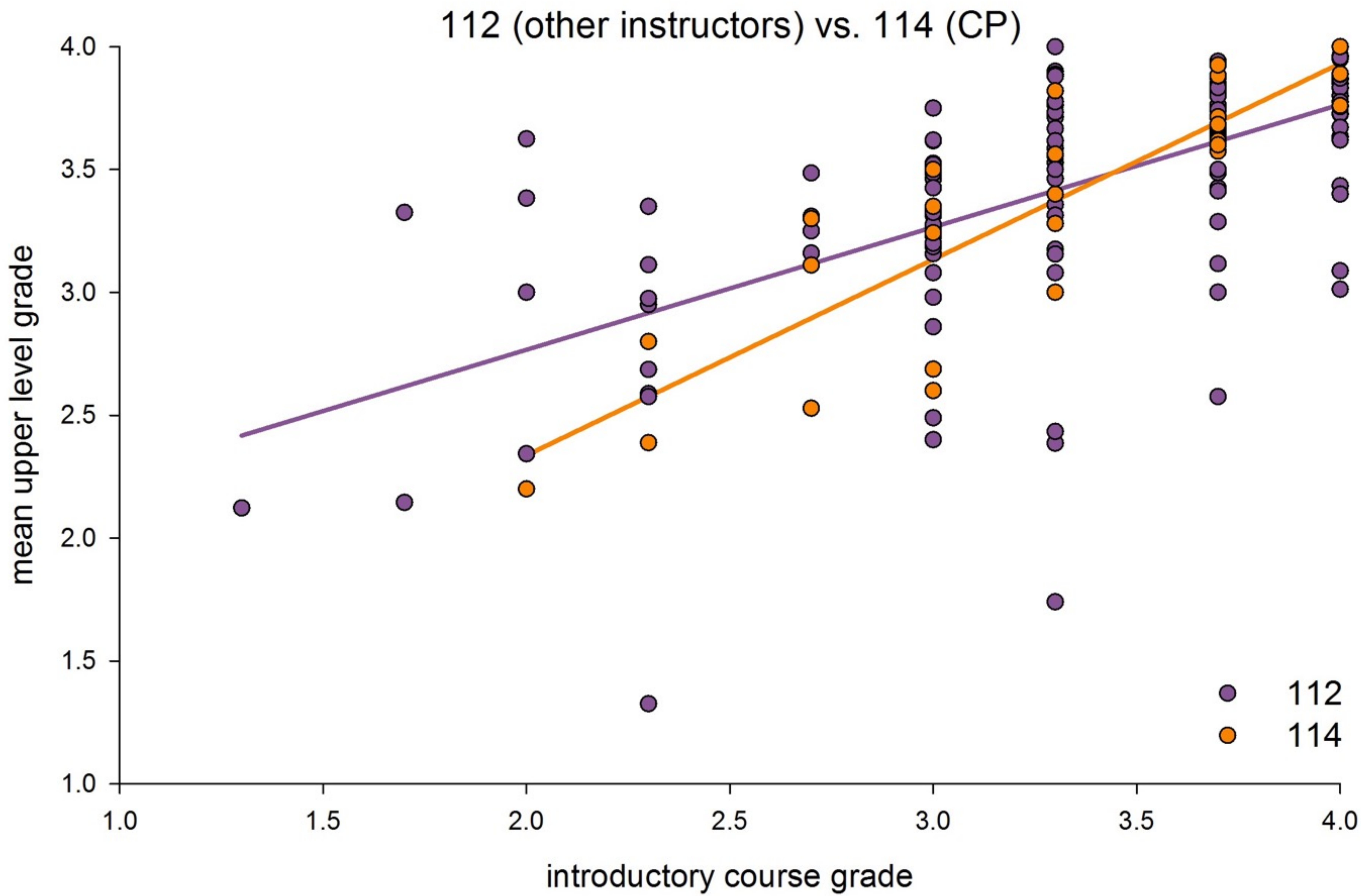
* p<0.05, ** p<0.01, *** p<0.001, ^ p= 0.06

Do *ICB* students do poorly in upper level?

Intro Grades Correlated to Upper Grades

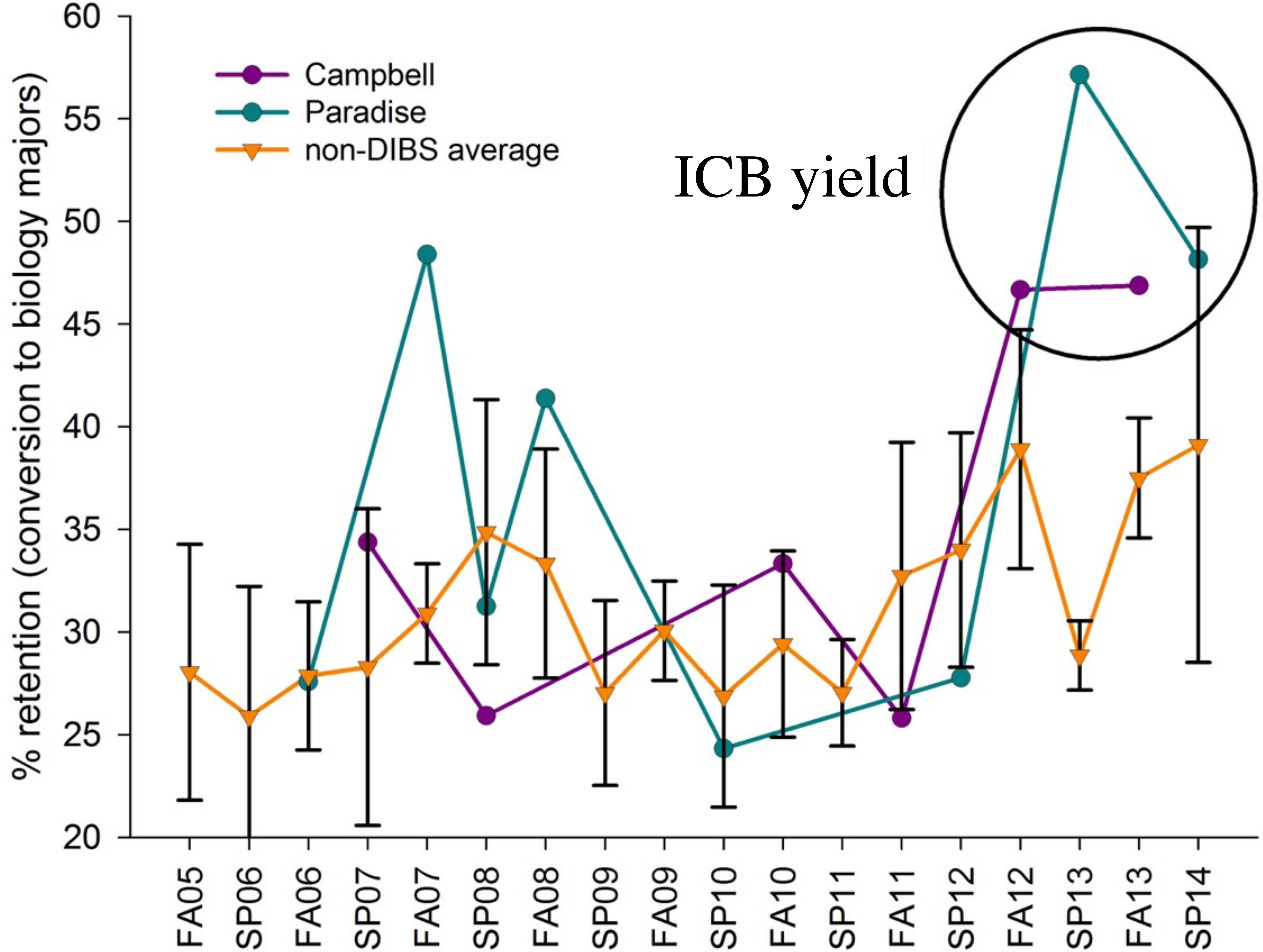


Intro Grades Correlated to Upper Grades



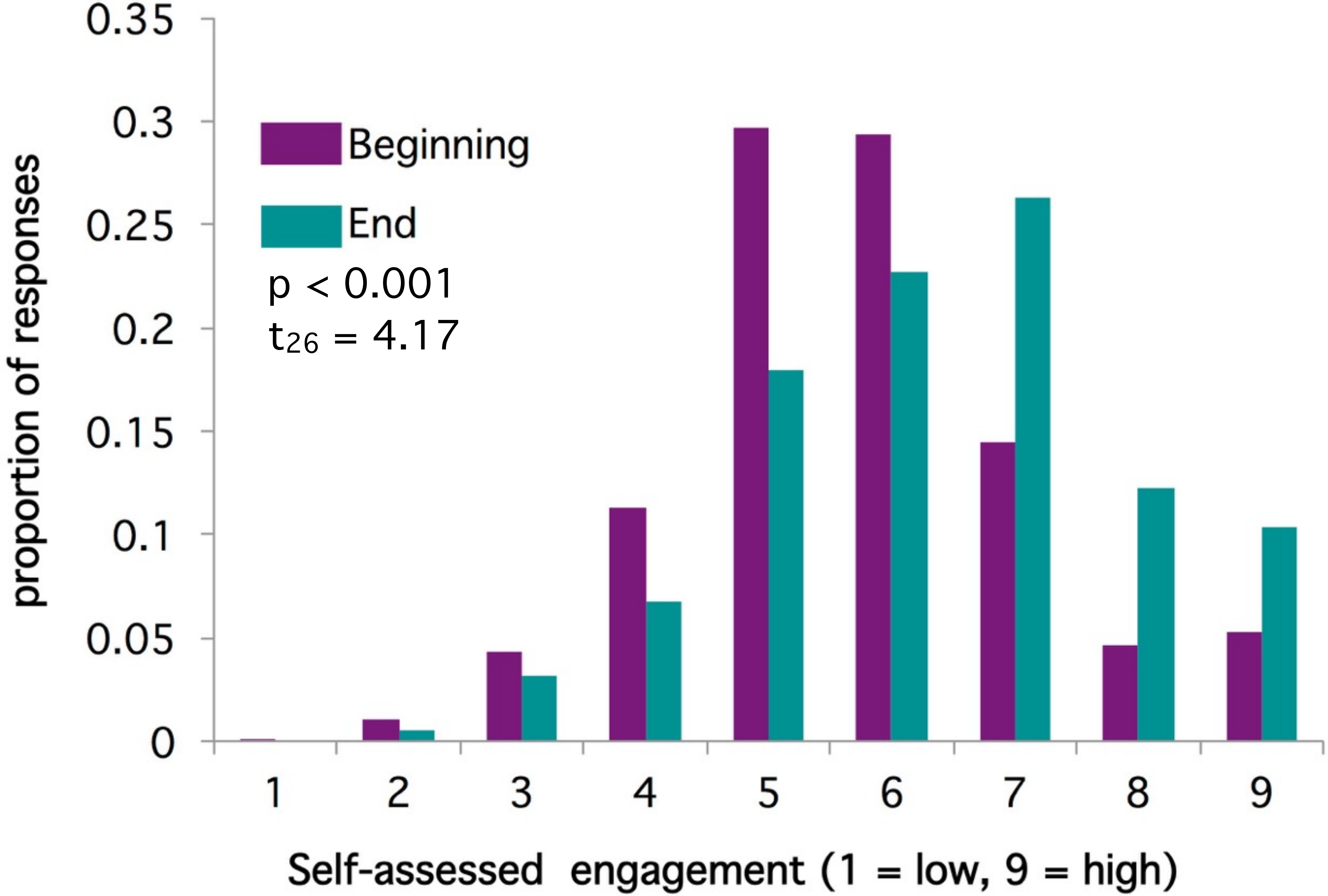
Does *ICB* chase away majors?

Compare *ICB* Yield for Majors

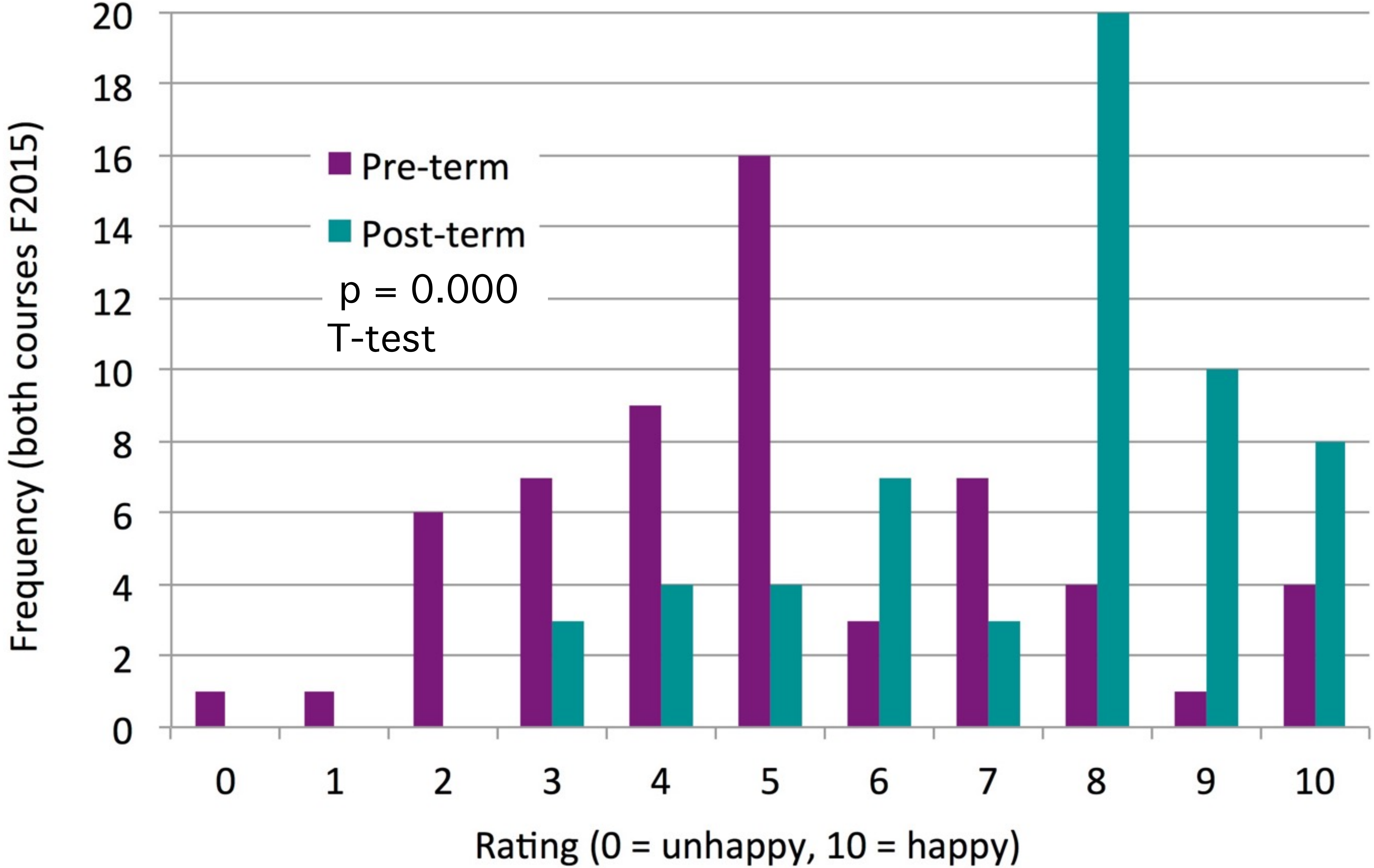


Do students like *ICB* approach?

Self-assessed Engagement Each class



Evaluate eBook Pre- and Post-semester



Our students accomplish Vision & Change Goals

Acknowledgements

Synthetic Biology Research

Laurie Heyer, Jeff Poet, Todd Eckdahl + undergrads!

xClone Plasmids

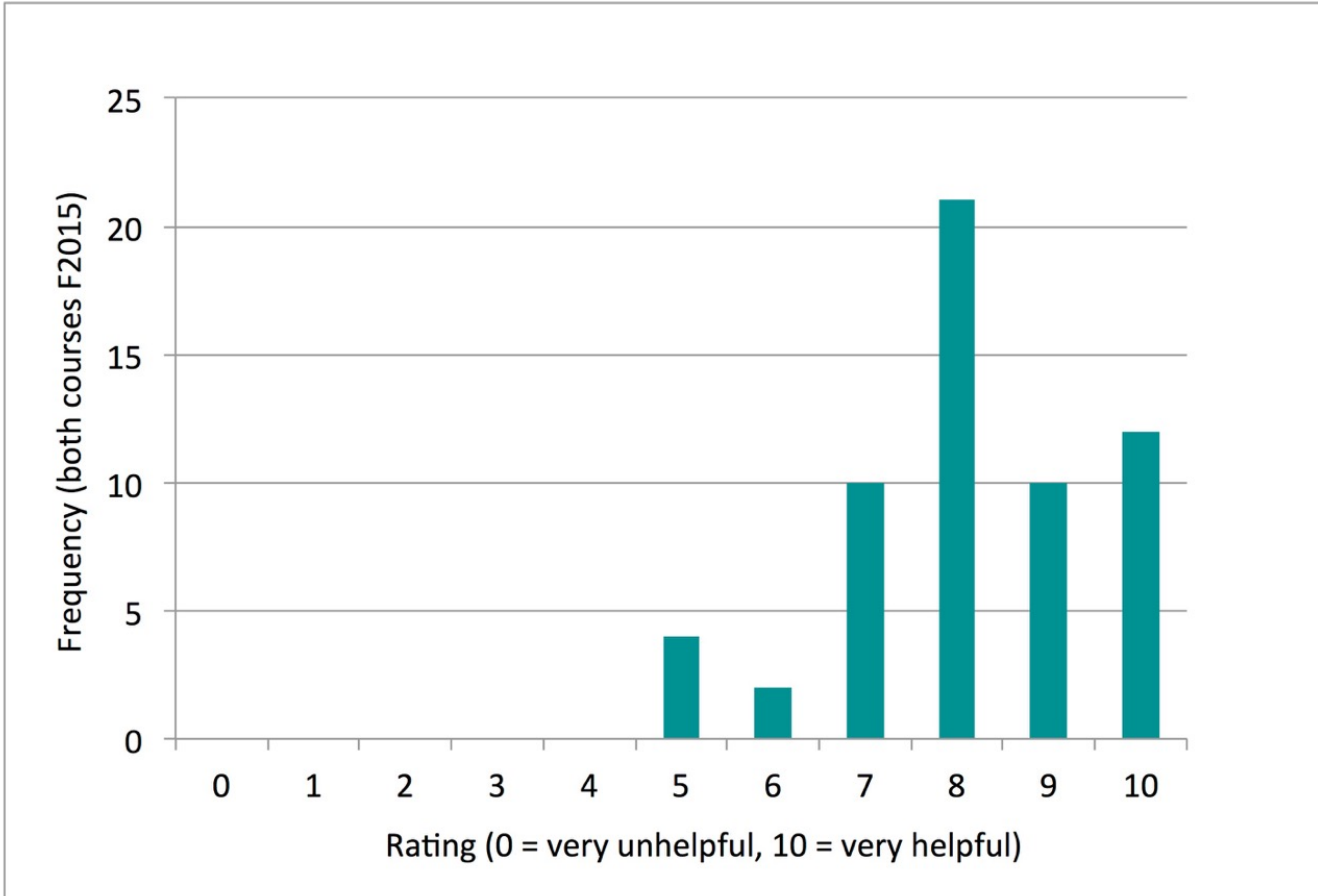
Todd Eckdahl + HS and undergrads!

ICB textbook and Research

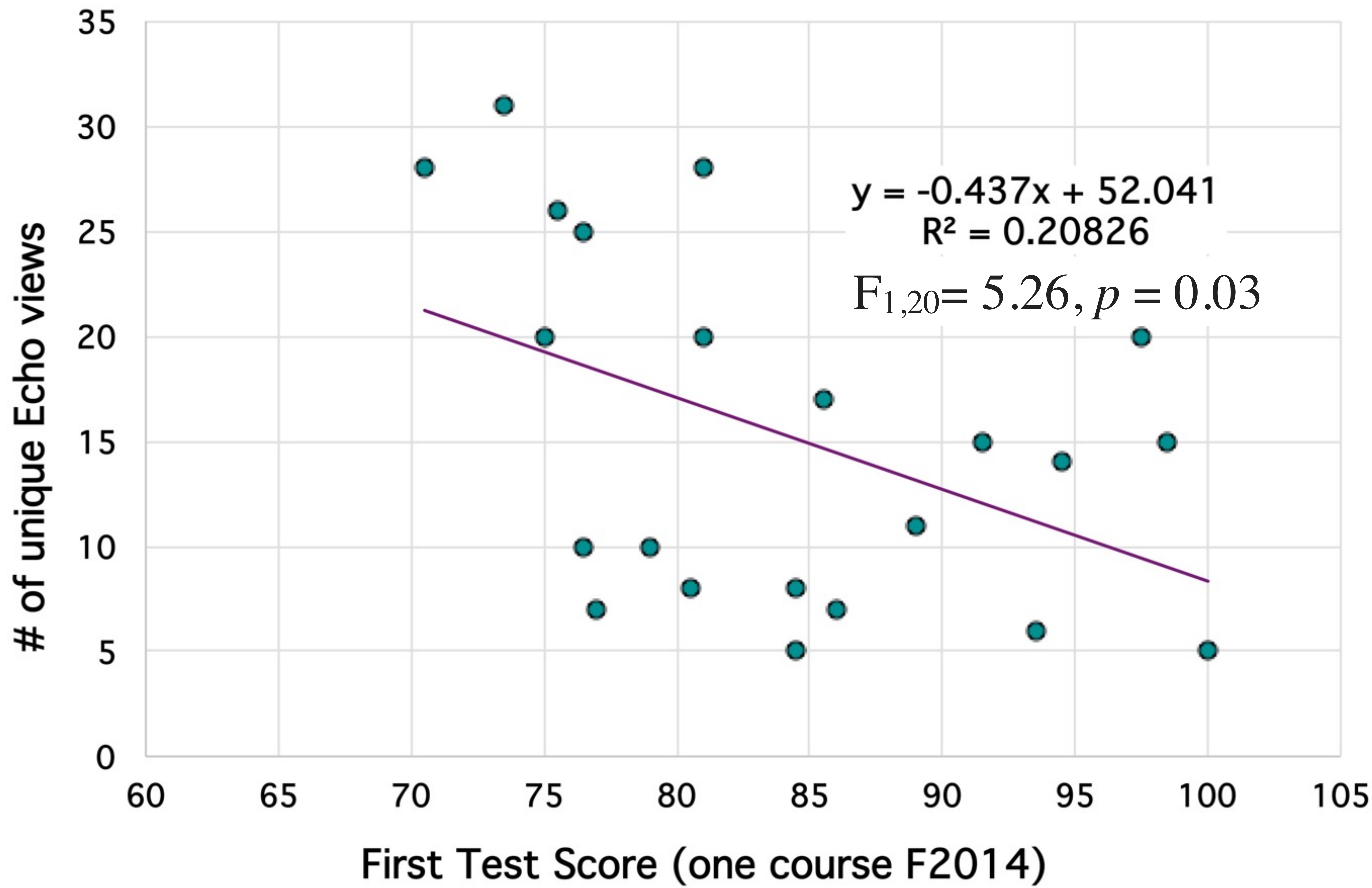
Laurie Heyer, Chris Paradise, Kevin Smith, Pat Sellars, Mark Barsoum, Caylyn Harvey, Kyosung Koo, Kristen Eshelman,

What affect does Echo360 have?

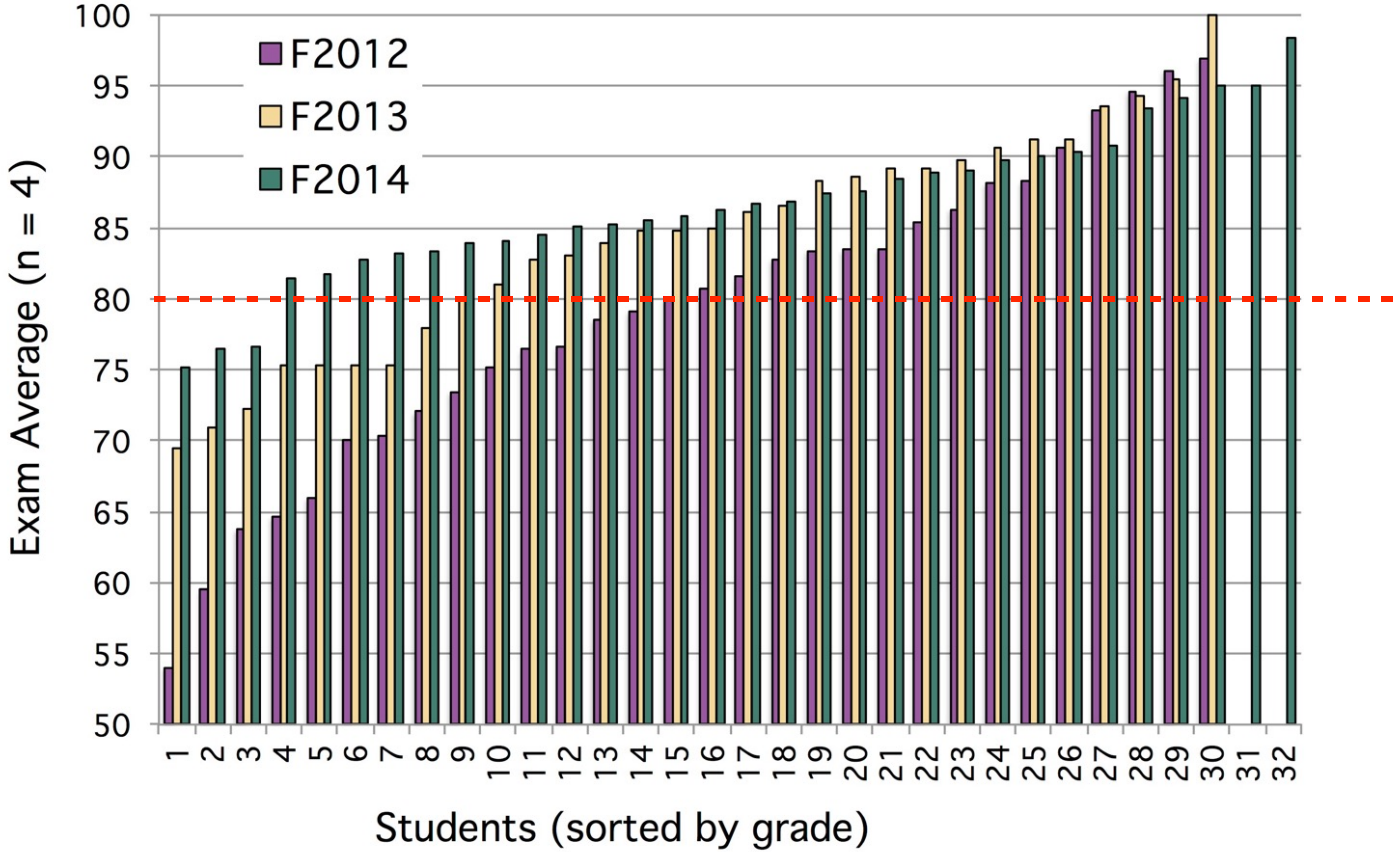
Students Liked Echo360



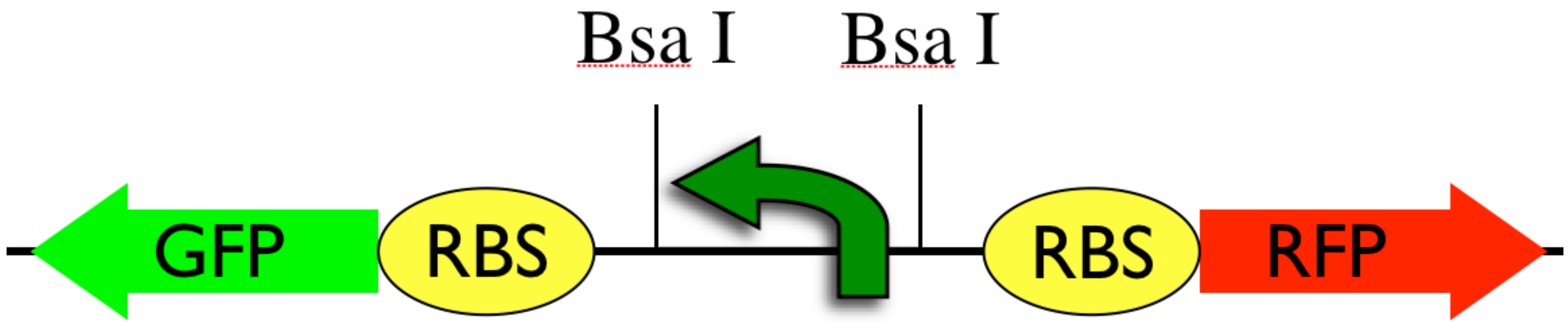
Lower Test Grade, Use Echo360 More

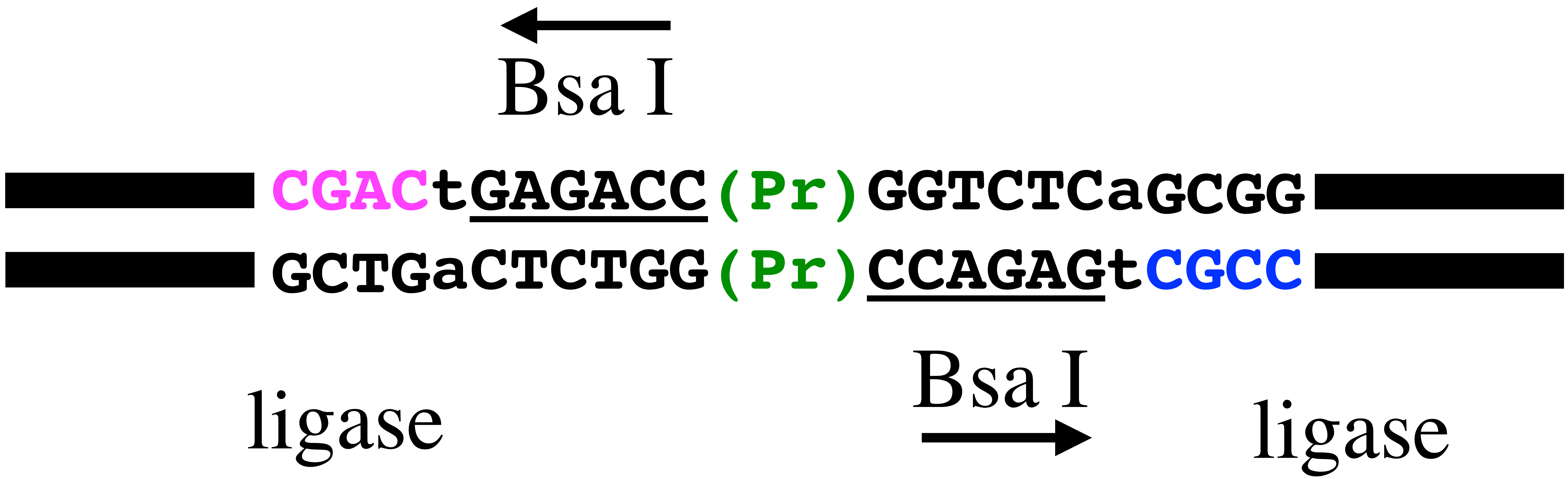


Great Impact on Student Grades



pClone Red

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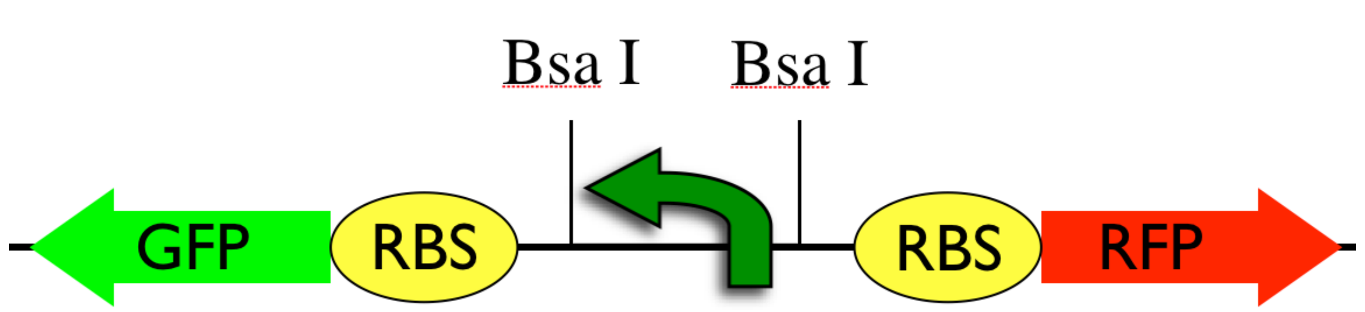
GCTGaCTCTGG(Pr)CCAGAGtCGCC
ligase
Bsa I
ligase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Bsa I
GFP
RBS
RBS
RFP

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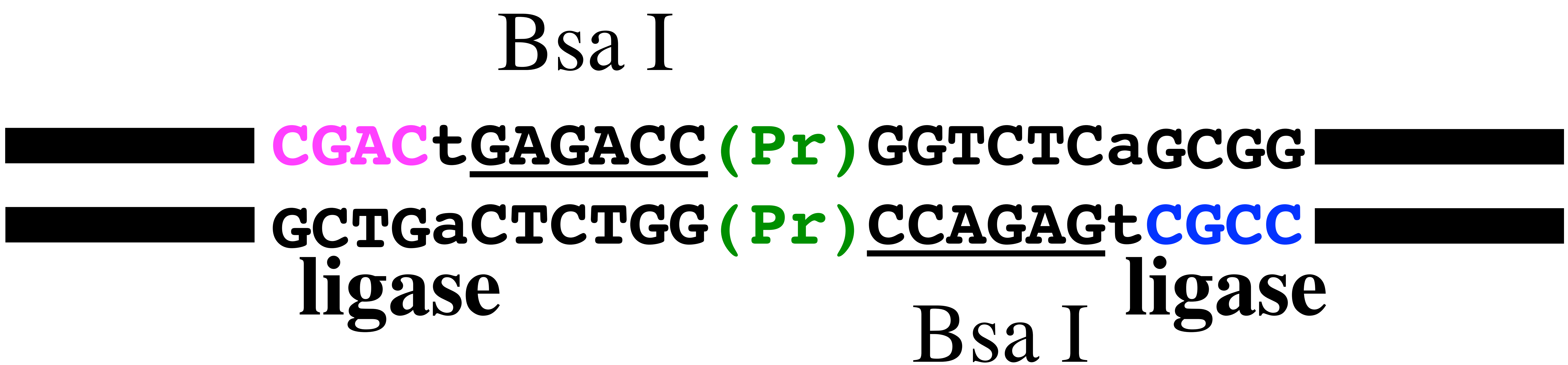
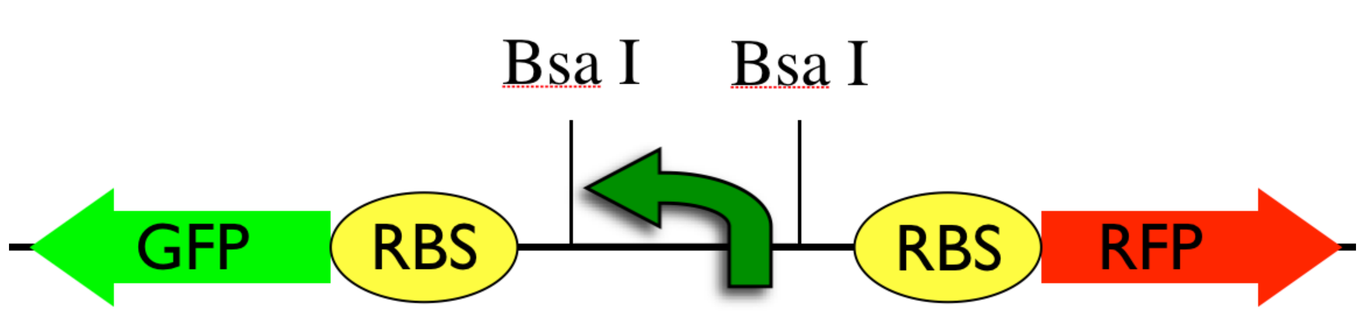
aCTCTGG(Pr)CCAGAGtCGCC

ligase

ligase


Bsa I
CGACtGAGACC(Pr)GGTCTCaGCGG
GCTGaCTCTGG(Pr)CCAGAGtCGCC
ligase
Bsa I
ligase


Bsa I
Bsa I
GFP
RBS
RBS
RFP

CGACt<u>GAGACC</u>(Pr)GGTCTCa

aCTCTGG(Pr)<u>CCAGAG</u>tCGCC

GCTG

GCGG

ligase

ligase

CGAC

CGAC

CGAC(promoter)GCGG

GCTG(promoter)CGCC

ligase ligase