Pimp My Genome!

The mainstreaming of digital genetic engineering

Andrew Hessel
Google Inc. May 3 2007
Biology is the study of life
Between 2 and 100 million species
We know virtually nothing about microorganisms

http://www.sciencedaily.com/releases/2003/05/030526103731.htm
The Sorcerer II Global Ocean Sampling Expedition: Northwest Atlantic through Eastern Tropical Pacific

Douglas B. Rusch³, Aaron L. Halpern¹, Granger Sutton¹, Karla B. Heidelberg¹,², Shannon Williamson¹, Shibu Yooseph¹, Dongying Wu¹,³, Jonathan A. Eisen¹,², Jeff M. Hoffman¹, Karin Remington¹,³, Karen Beeson¹, Bao Tran¹, Hamilton Smith¹, Holly Baden-Tillson¹, Clare Stewart¹, Joyce Thorpe¹, Jason Freeman¹, Cynthia Andrews-Pfannkoehl¹, Joseph E. Venter¹, Kelvin Li¹, Saul Kravitz¹, John F. Heidelberg¹,², Terry Utterback¹, Yu-Hui Rogers¹, Luisa I. Falcón⁵, Valeria Souza⁶, Germán Bonilla-Rosso⁶, Luis E. Eguarte⁶, David M. Karl⁶, Shubha Sathyendranath⁶, Trevor Platt⁷, Eldredge Bemingham⁶, Victor Gallardo⁶, Giselle Tamayo-Castillo⁶, Michael R. Ferrari¹, Robert L. Strausberg³, Kenneth Nealon¹,², Robert Friedman¹, Marvin Frazier¹, J. Craig Venter¹

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July 14, 2006

Made 1L LB Agar in order to make 500 mL (20 plates) of Ampicillin and 500 mL (50 plates) Kanamycin plates see post 265

Found H15 on plate #2 which is part Bba 1135,2A which is GFP with a constitutive promoter on PSB1 AR vector (KBC14 derived)

Amp Stock: 100 mg/mL
Kan Stock: 50 mg/mL

Final [Amp]: 100 μM (25 μL stock in 250 μL
Final [Kan]: 50 μM (125 μL stock in 250 μL)

Amp Plasmid is high copy number (100+)
Kan-R Plasmid is low copy number (10+)

Plasmids Transformed Today:

70. Bba-R0040 Constitutive Bancer (Strong)
30. Bba-R0034 High Copy RBS
11. Bba-R0034 In Terminator
H15 2A Bba-1135,2A GFP Device

Subscript is which plate the DNA for that part (plasmid) is
Device = Working System

Not using DH5α, using TOP10
Digital Biology

Genomics
Deoxyribonucleic Acid (DNA)

Nucleotide

Sugar-phosphate backbone

Base pairs

Sugar-phosphate backbone

Hydrogen bonds

Adenine

Sugar Phosphate Backbone

Base pair

Thymine

Nitrogeous base

Guanine

New strand

Cytosine

New strand

Source: Talking Glossary of Genetics
DNA is the machine language program for biochemical processes
Genomes are programs encoding:

- Biochemical processors
- Machinery to duplicate and install the program onto processors
<table>
<thead>
<tr>
<th>Organism</th>
<th>Bases</th>
<th>Genes</th>
<th>Gene Density</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Homo sapiens</em> (human)</td>
<td>2900 million</td>
<td>~30,000</td>
<td>1 gene per 100,000 bases</td>
<td>46</td>
</tr>
<tr>
<td><em>Rattus norvegicus</em> (rat)</td>
<td>2,750 million</td>
<td>~30,000</td>
<td>1 gene per 100,000 bases</td>
<td>42</td>
</tr>
<tr>
<td><em>Mus musculus</em> (mouse)</td>
<td>2500 million</td>
<td>~30,000</td>
<td>1 gene per 100,000 bases</td>
<td>40</td>
</tr>
<tr>
<td><em>Drosophila melanogaster</em> (fruit fly)</td>
<td>180 million</td>
<td>13,600</td>
<td>1 gene per 9,000 bases</td>
<td>8</td>
</tr>
<tr>
<td><em>Arabidopsis thaliana</em> (plant)</td>
<td>125 million</td>
<td>25,500</td>
<td>1 gene per 4000 bases</td>
<td>10</td>
</tr>
<tr>
<td><em>Caenorhabditis elegans</em> (roundworm)</td>
<td>97 million</td>
<td>19,100</td>
<td>1 gene per 5000 bases</td>
<td>12</td>
</tr>
<tr>
<td><em>Saccharomyces cerevisiae</em> (yeast)</td>
<td>12 million</td>
<td>6300</td>
<td>1 gene per 2000 bases</td>
<td>32</td>
</tr>
<tr>
<td><em>Escherichia coli</em> (bacteria)</td>
<td>4.7 million</td>
<td>3200</td>
<td>1 gene per 1400 bases</td>
<td>1</td>
</tr>
<tr>
<td><em>H. influenzae</em> (bacteria)</td>
<td>1.8 million</td>
<td>1700</td>
<td>1 gene per 1000 bases</td>
<td>1</td>
</tr>
</tbody>
</table>

*Information extracted from genome publication papers below.*

Genome size does not correlate with evolutionary status, nor is the number of genes proportionate with genome size.

http://www.ornl.gov/sci/techresources/Human_Genome/faq/compgen.shtml#genomesize
Reading code
1980
500 bp/day (manual)

1987
36,000 bp/day (semi-auto)

1995
144,000 bp/day (semi-auto)

1998
500,000 bp/day (automatic)

2007 – Sequencing by Synthesis
1GB bp/day (automatic)
The breakthrough of our lifetime... the X PRIZE about each of us.

Revolution Through Competition.
Comprehension

280.6 TFLOPS with 131072 nodes
Reduction  Complexity

http://www.linesandcolors.com/category/digital-art/
Biological understanding

• Just storing data is a challenge

• Finite human comprehension > finer specializations > greater barriers

• Machine-learning, self-organizing, and other naïve techniques increasing necessary – *Systems Biology*
“Perhaps surprisingly, a concise definition of systems biology that most of us can agree upon has yet to emerge.”

Ruedi Aebersold, Ph.D.
Faculty Member
Institute for Systems Biology
J.R. Koza et al.
Automatic creation of computer programs for designing electrical circuits using genetic programming.

Genetic “Engineering”

Writing code
If we can’t build it, we don’t understand it.
Biochemical Method for Inserting New Genetic Information into DNA of Simian Virus 40: Circular SV40 DNA Molecules Containing Lambda Phage Genes and the Galactose Operon of Escherichia coli

(molecular hybrid/DNA joining/viral transformation/genetic transfer)

DAVID A. JACKSON*, ROBERT H. SYMONS†, AND PAUL BERG

Department of Biochemistry, Stanford University Medical Center, Stanford, California 94305

Contributed by Paul Berg, July 31, 1972

First rDNA molecule reported, October 1972

Construction of Biologically Functional Bacterial Plasmids In Vitro

(R factor/restriction enzyme/transformation/endonuclease/antibiotic resistance)

STANLEY N. COHEN*, ANNIE C. Y. CHANG*, HERBERT W. BOYER†, AND ROBERT B. HELLING†

* Department of Medicine, Stanford University School of Medicine, Stanford, California 94305; and † Department of Microbiology, University of California at San Francisco, San Francisco, Calif. 94122

Communicated by Norman Davidson, July 18, 1973

First synthetic DNA molecule reported, November 1973
DNA vs Electronics

- Basic elements: DNA (1953/nobel ‘62) and transistor (1947/nobel ‘56)
- Similar potential for great influence on society
- Similar industry growth curves
Restriction Enzyme
Action of EcoRI
if you can write DNA,
you're no longer limited
to "What is"
but to what you could make
Coupling and Capping

Activation (acid) and new base addition

Controlled Pore Glass Solid Support
Milli GEN/Biosearch 8700 DNA Synthesizer

Seller of this item? Sign in for your status

Starting bid: US $89.99

End time: May 04, 07 08:30:40 PDT (1 day 7 hours)

Shipping costs: Check item description and payment instructions or contact seller for details

Ships to: United States

Item location: Saint Louis, Missouri, United States

History: 0 bids

You can also: Watch This Item

Get alerts via Text message, IM or Cell phone Email to a friend

Supersize
EGFP gene 714 bp
The graph compares the number of bases sequenced or synthesized per person per day to the number of transistors per chip from 1965 to 2010. The graph shows a significant increase in both metrics over time, with the number of transistors per chip growing exponentially. The sources of sequencing and synthesis technologies are indicated by different colors: red for number of transistors per chip, blue for commercially available sequencers, green for commercially available synthesizers, and purple for E Coli DNA Polymerase III.

Source: R. Carlson, Bio-era.
18 July 05. Method: Rough Google search. Thus not a thorough survey. No academic facilities.

Data Source: Rob Carlson, U of W, Seattle; www.synthesis.cc, rob@synthesis.cc

Some success

More success

Even more success

Engineering process…

• Electronics
• Software
• Aeronautics
• Structures
• Materials
• Automotives

refinement

complexity
Name: B0015  
Type: Double terminator  
Length 129 bp  
Designed by: Reshma Shetty  
Forward efficiency: 0.984  
Reverse efficiency: 0.295
Synthetic system or cell

F1760 Sender Device

B0015 terminator

ccaggcatcaaataaaacgaaaggctcagtcgaaagactgggcctttcgtttatatctgttgtttgtcggtgaacgctctctactagactgcactggctcaccttcgggtgggcctttctgcgtttata
### Transcriptional Regulators

#### Available repressible regulators (normally ON)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Direction</th>
<th>Control</th>
<th>Output Low</th>
<th>Output High</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBa_J14032</td>
<td>promoter P(Lac)1Q</td>
<td>Forward</td>
<td>aTc, tetracycline</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J0040</td>
<td>promoter (tetR, negative)</td>
<td>Forward</td>
<td></td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J0051</td>
<td>promoter (lambda cl regulated)</td>
<td>Forward</td>
<td>lambda cl</td>
<td>45</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Available inducible regulators (normally OFF)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Direction</th>
<th>Control</th>
<th>Output Low</th>
<th>Output High</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBa_J12007</td>
<td>Modified lambda Prm promoter (OR-3 obliterated)</td>
<td>Forward</td>
<td>cl</td>
<td>62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J0062</td>
<td>Promoter (luxR &amp; HSL regulated -- luxPr)</td>
<td>Forward</td>
<td>luxR, HSL</td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J0079</td>
<td>Promoter (LasR &amp; P1AI regulated)</td>
<td>Forward</td>
<td>P1AI</td>
<td>157</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J0080</td>
<td>Promoter (araC regulated)</td>
<td>Forward</td>
<td>araC</td>
<td>149</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Available other regulators

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Direction</th>
<th>Control</th>
<th>Output Low</th>
<th>Output High</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBa_J0500</td>
<td>inducible pBad/araC</td>
<td>Forward</td>
<td>araC, arabinose</td>
<td>1210</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J3453</td>
<td>pBAD promoter</td>
<td>Forward</td>
<td>araC</td>
<td>130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J3002</td>
<td>TetR repressed POPs/RIPS generator</td>
<td>Forward</td>
<td>ATc</td>
<td>74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J3023</td>
<td>3OC6HSL-LuxR dependent POPs/RIPS generator</td>
<td>Forward</td>
<td></td>
<td>117</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23100</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23101</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23102</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23103</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23104</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23105</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23106</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23107</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23108</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23109</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23110</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBa_J23111</td>
<td>constitutive promoter family member</td>
<td>Forward</td>
<td></td>
<td>35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

http://parts.mit.edu
BBa_F2620
3OC_HSL → PoPS Receiver

http://parts.mit.edu/registry/index.php/Part:BBa_F2620

Last Update: 15 January 2007

Description
A transcription factor (LuxR, BBa_C0062) that is active in the presence of cell-cell signaling molecule 3OC_HSL is controlled by a TetR-regulated operator (BBa_R0040). Device input is 3OC_HSL. Device output is PoPS from a LuxR-regulated operator. If used in a cell containing TetR then a second input signal such as aTc can be used to produce a Boolean AND function.

Characteristics
Input Swing: 1E-9 to 1E-6 M 3OC_HSL, exogenous
Output Swing: 0.1 to 500s1 GFP molecules cm-3 s-1
Switch Point: 7.1 mM 3OC_HSL, exogenous

LH Response: 5 min (50%), 27 min (90%)

Response Time*

Specificity*

Stability**

Demand (low/high input)
Translational: 256/8048 ribosomes cm-3

Compatibility
Chassis: Compatible with MC4100, MG1655, and DH5α
Plasmids: Compatible with pSB3K3 and pSB1A2
Devices: Compatible with E0240, E0430 and E0434
Cross talk with systems containing TetR (C0040)

Signaling: Crosstalk with input molecules similar to 3OC_HSL

Registry of Standard Biological Parts
making life better, one part at a time

License: Public
Shares:

- DNA parts
- DNA code
- Protocols
- Experience
- Publications
- Only one rule: share back!
2006 Jamboree – 400 gengineers
iGEM 2007

- 57 teams – 20 countries
- USA (26)
- Scotland (3)
- Colombia
- Italy (2)
- Mexico
- Taiwan
- Russia
- Germany
- South Africa
- Middle East
- Canada (6)
- Japan (2)
- Australia
- England
- Switzerland
- China (4)
- Spain
- India
- France
- Slovenia
COVER STORY

By Carl Zimmer

Jay Keasling is developing ways to program DNA as easily as people program computers.

GENETIC 'JAMBOREE' draws innovators

Science students the world over share research

Scientific American Life from scratch
Light Sensitive Signal Transduction

660nm

Cph 1

Env Z

OmpR

LacZ

OmpR

PompC

LacZ

Cph 1 chromophore biosynthesis

Phycocyanobilin

pcyA

to 1

heme

Black output
(G-gal)

Mercury vapor lamp

632nm bandpass filter

Double Gauss focusable lens

35mm slide

Projected image

Hello World
indole deficient tnaA5^- chassis

chorismate : SAGD \rightarrow \text{salicylic acid}

leucine : IAGD \rightarrow 3\text{-methylbutanal}

methyl salicylate

isoamyl alcohol

NADH \rightarrow \text{BSGD}

isoamyl acetate
The California Institute for Quantitative Biomedical Research (QB3) and Lawrence Berkeley National Laboratory (LBNL) have joined forces to accelerate the growth of synthetic biology, a new field that promises major new advances in preventing and treating disease, generating new energy sources, and preventing and mitigating environmental threats.

Opening in spring 2005 in a spacious, modern building in west Berkeley, the Berkeley Center for Synthetic Biology gives renowned scientists and engineers the chance to pool their talents and collaborate in new ways, with enormous potential benefits for California's citizens in the form of advances in biomedicine and energy renewables and economic growth.

Synthetic biologists study the control and design of biological components and new organisms to solve a host of important health, energy, and environmental problems that cannot be solved using naturally occurring biological entities. The inherently

MIT establishes groundbreaking biological engineering major

February 17, 2005

The Massachusetts Institute of Technology faculty yesterday approved a new course of study for undergraduates, in biological engineering, the first entirely new curriculum established at the Institute in 29 years.
OpenWetWare is an effort to promote the sharing of information, knowledge, and wisdom among researchers and groups who are working in biology & biological engineering. Learn more about us [here](#).

If you would like edit access, would be interested in helping out, or want your lab website hosted on OpenWetWare, please [join us](#).
Looking forward
Recombinant DNA technology:
- Horizontal transfer of genetic material
- Homologous recombination
- Gene shuffling/directed evolution

Synthetic biology techniques:
- Standard biological parts
- Low cost sequencing and synthesis
- Simplified chasses/operating systems
- System modeling and simulation
- Metabolic pathway design

Source: Bio era
<table>
<thead>
<tr>
<th>Driving Forces</th>
<th>Major Uncertainties</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Rapid advance of DNA sequencing, synthesis, and other enabling technologies</td>
<td>• How quickly will biological engineering advance?</td>
</tr>
<tr>
<td>• Global growth of biotech R&amp;D, knowledge, and applications</td>
<td>• Will governments attempt to restrict access to advanced biotech tools?</td>
</tr>
<tr>
<td>• Geopolitics; new security concerns</td>
<td>• How will public attitudes toward biological engineering evolve?</td>
</tr>
<tr>
<td>• Energy prices and climate change</td>
<td>• Will the assertion of intellectual property rights slow innovation in synthetic biology?</td>
</tr>
<tr>
<td>• Urbanization and industrialization in developing economies</td>
<td>• Will terrorists or governments use genome engineering techniques to create biological weapons?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Predetermined Elements</th>
<th>Prime Movers</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Increasing environmental stress on global ecosystems</td>
<td>• U.S. government: DOE, NIH, NSABB, USPTO</td>
</tr>
<tr>
<td>• Growing infectious disease threats to human and animal populations</td>
<td>• Biological engineering researchers</td>
</tr>
<tr>
<td>• Human curiosity &amp; technical innovation</td>
<td>• “Open source” biology community</td>
</tr>
<tr>
<td>• Growing healthcare needs of aging populations</td>
<td>• Bioterrorists</td>
</tr>
<tr>
<td></td>
<td>• Energy, chemical, and pharmaceutical industries</td>
</tr>
</tbody>
</table>
**The Gilded Lab:**

Public and private funding supports laboratory research programs, but biological engineering meets challenging technical obstacles; economic implications are small and investors are disappointed.

**Modular Life:**

Abundant entrepreneurial entry and new product creation; application of biological engineering in many sectors of the economy; some applications create social controversy and opposition.

**Barricades:**

Geopolitical tensions and security concerns dominate government policy; genome engineering research is severely restricted, with limited commercial activity; government-funded research is focused on biodefense.

**Underworld:**

Like the Prohibition Era; government efforts to restrict the technology foster black markets, hacker culture, and lots of unregulated activity outside the U.S.
Essential genes of a minimal bacterium


Synthetic Biology Group, J. Craig Venter Institute, 9704 Medical Center Drive, Rockville, MD 20850

Contributed by Hamilton O. Smith, November 18, 2005

*Mycoplasm a genitalium has the smallest genome of any organism that can be grown in pure culture. It has a minimal metabolism and little genomic redundancy. Consequently, its genome is expected to be a close approximation to the minimal set of genes needed to sustain bacterial life. Using global transposon mutagenesis, we isolated and characterized gene disruption mutants for 100 different nonessential protein-coding genes. None of the 43 RNA-coding genes were disrupted. Herein, we identify 382 of the 482 M. genitalium protein-coding genes as essential, plus five sets of disrupted genes that encode proteins with potentially redundant essential functions, such as phosphate transport. Genes encoding proteins of unknown function constitute 28% of the essential protein-coding genes set. Disruption of some genes accelerated M. genitalium growth.

urogenital pathogen, is the extreme manifestation of this genomic parsimony, having only 482 protein-coding genes and the smallest genome, at \( \sim 580 \) kb, of any known free-living organism capable of being grown in axenic culture (13). Although more conventional bacteria with larger genomes used in gene essentiality studies have on average 26% of their genes in paralogous gene families, M. genitalium has only 6% (Table 1, which is published as supporting information on the PNAS website). Thus, with its lack of genomic redundancy and contingencies for different environmental conditions, M. genitalium is already close to being a minimal bacterial cell.

In our 1999 report (4) on the essential microbial gene for M. genitalium and its closest relative Mycoplasma pneumoniae, we mapped \( \sim 2,200 \) transposon insertion sites in these two species, and identified 130 cyanobacterial-like genes encoding
Next generation biotechnology industry?
Welcome

Amyris Biotechnologies is translating the promise of synthetic biology into solutions for real-world problems. Building on advances in molecular, cell and systems biology, we are engineering microbes capable of producing high-value compounds to address major global health and energy challenges. We are employing these living chemical factories to produce novel pharmaceuticals, renewable fuels, and specialty chemicals.
The Methuselah Foundation is a non-profit 501(c)(3) volunteer organization dedicated to raising public awareness of the near-term potential for evidence-based interventions in the aging process. To this end, we perform research focused on repairing the damage that accumulates at the cellular and molecular level with time causing age-related dysfunction, and offer the multi-million dollar Methuselah Mouse Prize (Mprize) for significant, scientifically reproducible life extension in already aged lab mice.
TIME

COMPUTER GENERATION

A New Breed of Whiz Kids
ADVENTURES IN SYNTHETIC BIOLOGY

ENGINEERED GENETIC DEVICES

OK, PAY ATTENTION! AN INVERTER IS A COMBINATION OF BASIC DNA PARTS THAT:

1. Transcription Factor Binding Site (TFBS) - Basic elements that start the process of protein synthesis.
2. Repressor - A gene that encodes a protein that will bind DNA sites in a specific promoter region and cause changes in the rate of gene expression.
3. Operator - A switch that controls the presence or absence of a Repressor protein binding site and RNA polymerase binding and initiation.
4. terminator - A signal that stops transcription. This is an example of a Repressor protein binding site and RNA polymerase binding site that can turn off transcription.

Parts of an Inverter

OMG... WHOA! IT'S A DEVICES!

FOR EXAMPLE, HERE'S SOME DNA CODE:

YOU COULD HAVE USED AN INVERTER DEVICE TO HELP PREVENT BUDDY'S UNFORTUNATE ACCIDENT.

WHAT THE HECK IS AN INVERTER?

IT COULD BE THE ANSWER YOU'RE LOOKING FOR.

LET ME INTRODUCE YOU TO A FRIEND OF MINE. IT'S CALLED AN INVERTER DEVICE.

YOU COULD HAVE USED AN INVERTER DEVICE TO HELP PREVENT BUDDY'S UNFORTUNATE ACCIDENT.

WHAT THE HECK IS AN INVERTER?

IT COULD BE THE ANSWER YOU'RE LOOKING FOR.

OK, PAY ATTENTION! AN INVERTER IS A COMBINATION OF BASIC DNA PARTS THAT:

1. Transcription Factor Binding Site (TFBS) - Basic elements that start the process of protein synthesis.
2. Repressor - A gene that encodes a protein that will bind DNA sites in a specific promoter region and cause changes in the rate of gene expression.
3. Operator - A switch that controls the presence or absence of a Repressor protein binding site and RNA polymerase binding and initiation.
4. terminator - A signal that stops transcription. This is an example of a Repressor protein binding site and RNA polymerase binding site that can turn off transcription.

Parts of an Inverter

OMG... WHOA! IT'S A DEVICES!

FOR EXAMPLE, HERE'S SOME DNA CODE:

YOU COULD HAVE USED AN INVERTER DEVICE TO HELP PREVENT BUDDY'S UNFORTUNATE ACCIDENT.

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Projects with DNA

For ages 8 and up
Adult Supervision Required
Materials included except for the items listed.
Through play, hands-on projects, patterns and puzzles
this book and kit explores the amazing DNA story.

- Extract DNA
- Heat SHOCK!
- Build a DNA ladder
- Decode the code of life
- Grow glowing cells
- Is it a boy or girl?
- Dress up for sterile techniques
- Ooey, Gooey, DNA!

Quality time, quality learning, quality play.

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