

Gene Switches—A Model

Abstract

Conceptually, how genetic switches function and their role in the process of evolution, can be difficult for students to visualize. *Gene Switches—A Model* attempts to make all of this more understandable through the use of clips from the HHMI DVD *Evolution: Constant Change and Common Threads* and the construction of a model. This activity can be done as a demonstration, a student inquiry activity, or a combination of the two.

Appropriate Grade Level

High School Biology – average, honors, and AP
Undergraduate Biology

Goals

This activity is designed to engage students in thinking about the following:

- What role does variation play in the evolution of a species?
 - Why are some variations inherited and others eliminated?
 - How do variation, selection, and time fuel the process of evolution?
 - What is the role of gene switches in evolution?
 - How do gene switch mutations lead to the evolution of a species?
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Time Requirement

This activity consists of two distinct parts.

- Part One requires one 45-minute block of time.
 - Part Two can be done in class or as homework. It will require approximately 45 minutes.
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Required Student Background Information

- evolution and natural selection
 - variation within a species
 - mutations
 - DNA
 - protein synthesis
 - genes
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Materials

- Computer with DVD drive and LCD projector or DVD player and LCD projector or monitor. An alternative to the DVD is a computer with access to the Internet
- Assorted materials for constructing models. These might include clay (such as Play-doh or clay, yarn, pipe cleaners, plastic beads, paperclips, etc.). Another option is FridgiGears. They can be purchased online at many toy and science stores.

If using FridgiGears, you will need a magnetic white board. These are available online from office supply stores. Enter “magnetic white board” into any search engine for multiple results.

If using FridgiGears, you will also need

- Several 12” lengths of yarn
 - Photocopied sets of gears (1 large blue, 2 medium-large yellow, 4 medium, and 4 or 5 small gears of various colors) Provide enough sets so that students can work in teams of two. Gear templates appear at the end of the Teacher materials.
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Background Information

All genes are tightly regulated. One major mechanism that plays a key role in this regulation is the genetic switch. Switches allow genes to be on in one tissue but off in another. It is a major field of current research to understand to what extent changing these switches drives evolution.

Sean Carroll, Ph.D. and David Kingsley, Ph.D. hypothesize that evolution happens, not by making new genes but by changing switches to do new things with existing genes. Several examples of where and how this has occurred are discussed during Dr. Carroll's and Dr. Kingsley's presentations that are part of the HHMI DVD 1 of *Evolution: Constant Change and Common Threads*. Click on *Animations* located in the DVD's main menu to view relevant parts of the lectures. These include the animations: *Gene Switch*, *Pitx1 Expression*, and *Paintbrush Gene*. Also click on *Video Clips* in the Main Menu and view *Stickleback Environment*. These are what students will be directed to watch as they work through this activity. Also of interest are the video clips *Fruit Fly Courtship 1* and *2*.

Additional Background Information

Evolution's Mirror in a Fish's Spines April 15, 2004

<http://www.hhmi.org/news/kingsley3.html>

Of Fish and Men by Sarah Williams May 2008

<http://www.hhmi.org/bulletin/may2008/chronicle/fish.html>

Same Genetic Machinery Generates Skin Color Evolution in Fish and Humans December 14, 2007

<http://www.hhmi.org/news/kingsley20071214.html>

Implementing the Activity

- (a) Ask students how it is that individuals in a population of the same species exhibit variations in traits. The students should know that variations are due to the recombination of genetic alleles during sexual reproduction and mutations.
- (b) Next ask students to describe what a mutation is. Also discuss how a mutation can result in new traits. It is likely they will focus on gene mutations...those that occur in the coding sequence of a gene. That's OK at this point.
- (c) Provide students with the handout ***Gene Switches—A Model***. Either work through the animations and video clips with entire class or have students work in pairs.

Their primary task is to answer the question, "What is the role of gene switch mutations in the evolution of a species?"

- (d) First have them view the ***Gene Switch*** animation. There are two ways to access this and all the other video clips and animations used in this activity.

Method 1: Load disc 1 of *Evolution: Constant Change and Common Threads*.

Click on *Animations* located at the bottom of the *Main Menu* screen.

After clicking on *Animations*, click on *More* located in the lower right corner of the screen and view the animation with the title *Gene Switch*.

Method 2 Go to <http://www.hhmi.org/biointeractive/evolution/animations.html>.

Show the *Gene Switch* animation again.

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- (e) Discuss the information in the *A Model Organism—Stickleback Fish* section of the student activity. To learn more about these fish, have students view the video clip ***Stickleback Environment****
- Go to the main menu of *Evolution: Constant Change and Common Threads*.
 - Click on *Video Clips* and go to the second screen by clicking on *More*.
 - Discuss with students question 1. What environmental factor seems to have influenced whether groups of sticklebacks have kept or lost some of their armor?
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- (f) Discuss the scenario described in the student reading *Some Old Fossils—Stickleback Fish*. Emphasize that the fossil record clearly shows that on two separate occasions in this former lake stickleback fish evolved a reduced pelvis. Then have students watch the video ***Fossil Record of Stickleback Evolution***.*
- Go to main menu of *Evolution: Constant Change and Common Threads*.
 - Click on *Video Clips* and go to the second screen by clicking on *More*.
 - Discuss with students some possible reasons the reduced pelvis variation was favored. You might want to mention that making armor is an expensive business. It requires extra intake of minerals such as salts. In a freshwater lake, it could be a limiting factor.
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- (g) Have students view ***Pitx1 Expression****
- Go to *Main Menu*, click on *Animations*
 - Go to the second screen where the animation is located by clicking on *More*.
 - Discuss with students question 2. How are gene switches involved in determining which sticklebacks possess armor and which do not? Does this cause a change in the protein coded for by the gene?
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- (h) Have students view the animation ***Paintbrush Gene****
- It is located on the third screen in the *Animations* feature
 - To help students with the question about how the presence or absence of spots might influence the evolution of fruit fly species (question 3), show them the videos *Fruit Fly Courtship 1 and 2**, found under *Video Clips* on the main menu.
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***Note:** You can also find the video clips and animations on HHMI's BioInteractive web site.

- *Fossil Record of Stickleback Evolution:* <http://www.hhmi.org/biointeractive/evolution/animations.html>
 - *Gene Switch:* <http://www.hhmi.org/biointeractive/evolution/animations.html>.
 - *Stickleback Environment:* <http://www.hhmi.org/biointeractive/evolution/video.html>
 - *Pitx1 Expression:* <http://www.hhmi.org/biointeractive/evolution/animations.html>
 - *Paintbrush Gene:* <http://www.hhmi.org/biointeractive/evolution/animations.html>
 - *Fruit Fly Courtship 1 and 2:* <http://www.hhmi.org/biointeractive/evolution/video.html>
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Possible Answers to Questions:

1. *What environmental factor seems to have influenced whether groups of sticklebacks have kept or lost some of their armor?*

The type of predators present seems to influence whether armor confers advantages or disadvantages and determine whether or not armor is reduced in a population.

2. *How are gene switches involved in determining which sticklebacks possess armor and which do not? Does this cause a change in the protein coded for by the gene?*

A mutation in a switch causes a gene to no longer be expressed in some locations. This results in the absence of specific structures such as armor and hind limbs. There is no change in the protein coded for by the gene. It is a matter of where and when the protein is synthesized.

3. *How are gene switches involved in the presence of spots on the wings of some fruit fly species and not on the wings of other species? How might the presence or absence of spots influence the evolution of these species?*

In the flies with wing spots, there is a new switch that expands the job of the of the paintbrush gene. In addition to pigmenting the abdomen of the fly, the same gene now also pigments the wings. It is a matter of when and where the gene is turned on.

Wing spots play a role in the courtship ritual of the flies. Females of the species with wing spots will not be attracted to males lacking the spots. The reverse is also true. Therefore those with and without wing spots are isolated reproductively.

4. *Explain how gene switch mutations could lead to the evolution of a species?*

Depending on their science background, the depth of student answers will vary. Students should focus on the idea that gene switches determine when and where various genes turn on and off. When a gene switch is added or deleted, new variations result. Some of these variations will be favorable and enhance the ability of the organism to survive and reproduce, thus passing this new trait on to its offspring. Over time, these variations can result in speciation.

Glossary

Coding DNA: A sequence of DNA that codes for a protein is known as coding DNA. These sections of coding are also referred to as exons.

mRNA: Messenger ribonucleic acid is a single stranded RNA molecule that encodes the amino acid sequence of a protein. mRNA is transcribed from a DNA template and carries coding information from the DNA to the ribosomes where proteins are synthesized.

Noncoding DNA: Noncoding DNA is part of DNA that is not eventually translated into amino acids. If the noncoding sections are part of a gene, they are referred to as introns. Introns are transcribed into mRNA along with exons, but are spliced out so they are never translated. DNA sequences between genes are also noncoding DNA. Generally, these sections of DNA are not even transcribed into mRNA. It is now known that some noncoding DNA is involved in regulating the activity of regions of coding DNA. For example, in eukaryotes, noncoding DNA encodes signals that regulate chromosome assembly, DNA replication, and gene expression.

***Pitx-1* Gene:** *Pitx1* (Paired-like homeodomain transcription factor 1) is a homeobox gene found in all vertebrates. The protein it encodes is a transcription factor that regulates the expression of other genes involved in development. Specifically, it is involved in the development of the pituitary gland, the jaw, the thymus, and the hind limbs. Mutations are associated with cleft palate and clubfoot. Freshwater sticklebacks express the *Pitx1* gene in all the same tissues as the marine stickleback except

those that develop into pelvic structures.

Promoter: A promoter is a region of DNA that acts as a controlling element in the expression of a gene. It facilitates transcription. A promoter is typically located a short distance upstream from the gene it regulates.

Regulatory Molecule: A regulatory molecule is a protein that modulates the activity of a group of enzymes including kinases and proteases.

RNA polymerase: RNA polymerase is an enzyme that catalyzes the synthesis of RNA. In eukaryotes, RNA polymerases are DNA dependent, meaning they use DNA as a template during transcription. In some viruses, RNA may serve as the template.

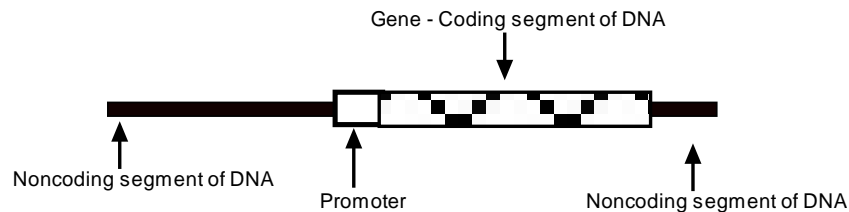
Constructing a Gene Switch Model

- (i) Introduce the model development phase of this activity. Review with students what a scientific model is. Also discuss how you will use the scoring guide to evaluate the accuracy and effectiveness of the models the class develops.

Provide them with an overview of the materials you have available and tell them they can use other materials if they want. They should clear these materials with you before going forward with their work.

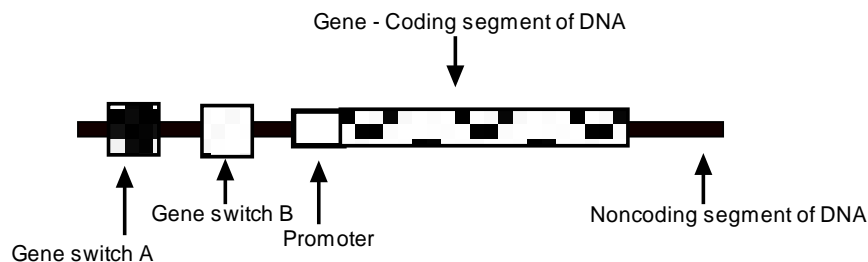
The following series of illustrations may be helpful to some students when developing their models.

Figure 1: Diagram of segment of DNA including a gene



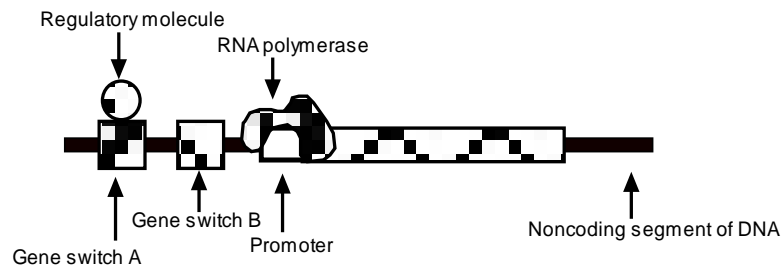
- A gene is a coding segment of DNA.
- One non-coding segment is the promoter.

Figure 2: Diagram of a gene with switches



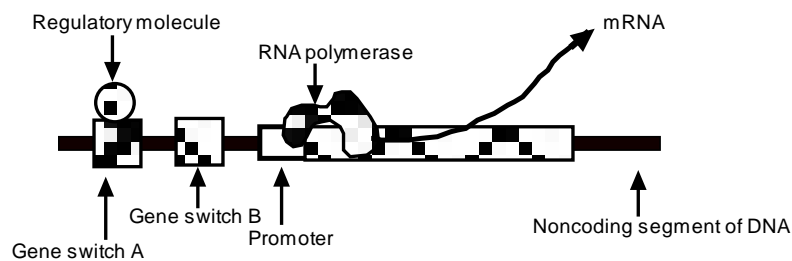
- Genes are surrounded by multiple switches. Genetic switches can be either upstream or downstream from a gene. In the animations and lectures on the DVD and in the illustrations on these pages, the gene switches are shown only upstream for convenience and simplicity.

Figure 3: Gene switch with regulatory molecule



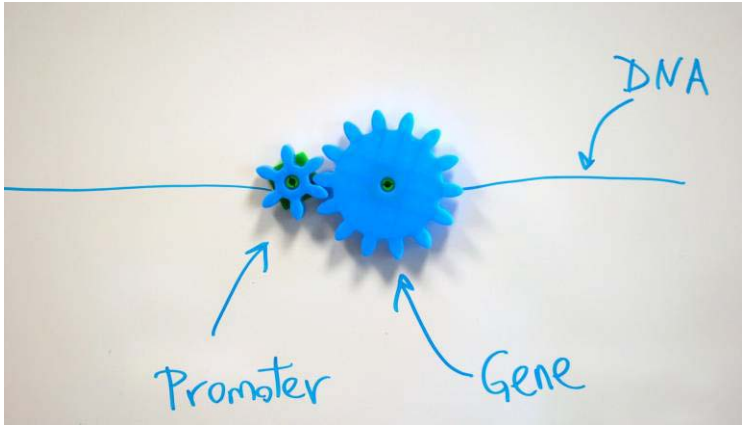
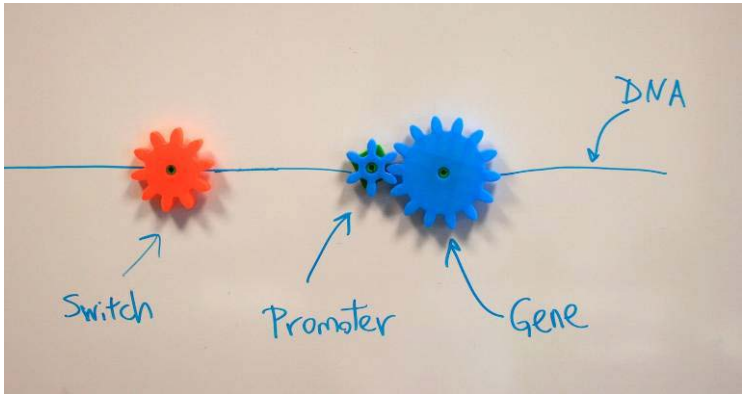
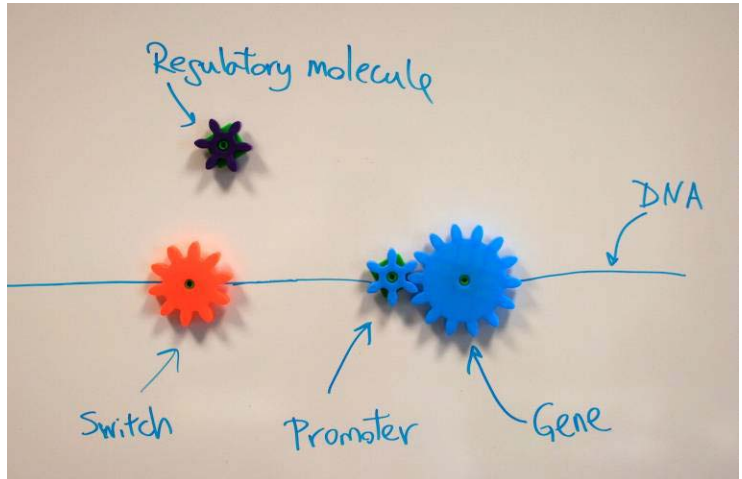
- Gene switches determine when and where each gene is turned on.
- Gene switches are the binding sites for regulatory molecules.
- When the appropriate regulatory molecule lands on a gene switch, the switch recruits RNA polymerase to the promoter. (You can see this in action in the *p53* animation for cancer at: <http://www.hhmi.org/biointeractive/media/p53-1g.mov>. In this case, p53 is the regulatory molecule. The p53 binding site is the switch.)
- RNA polymerase lands on the promoter.

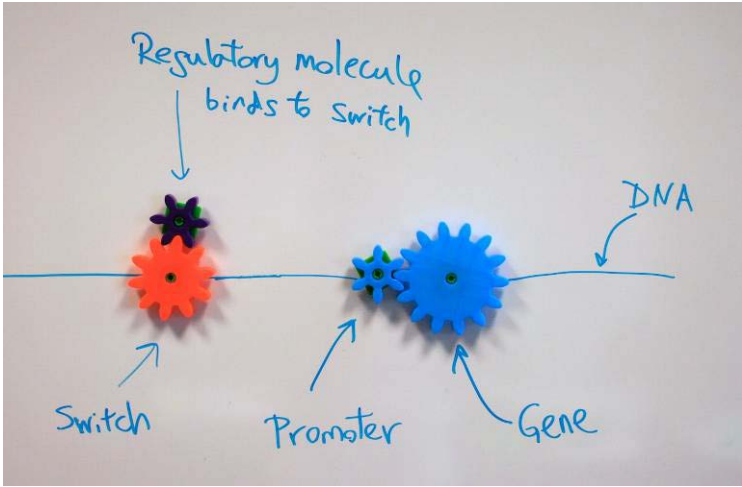
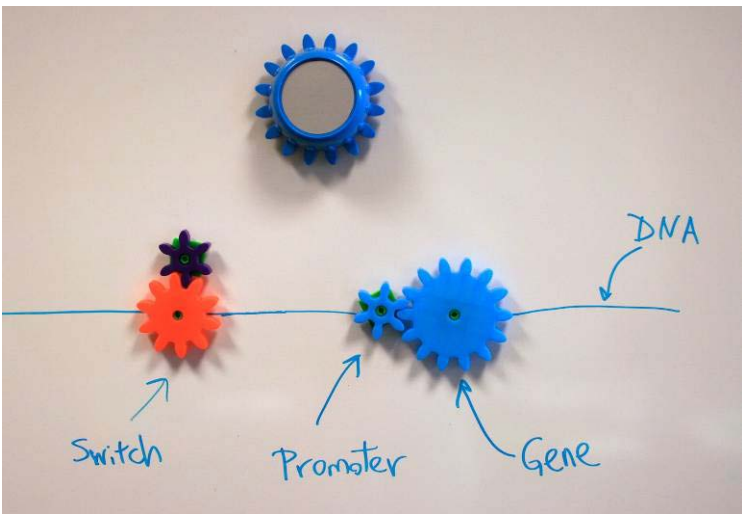
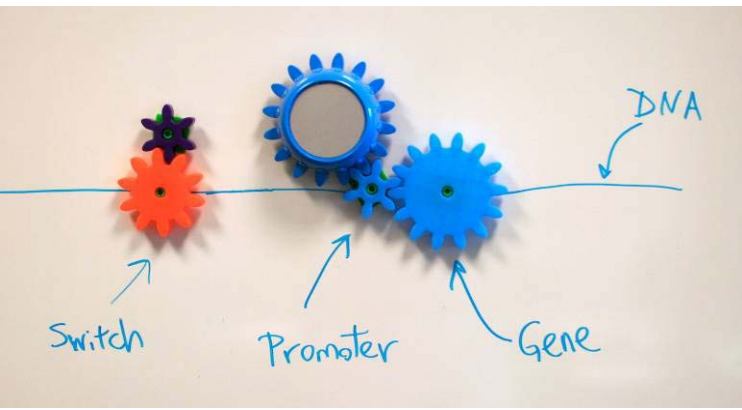
Figure 4: mRNA is made—gene is expressed



- The RNA polymerase transcribes the gene into mRNA, thus “expressing” the gene.

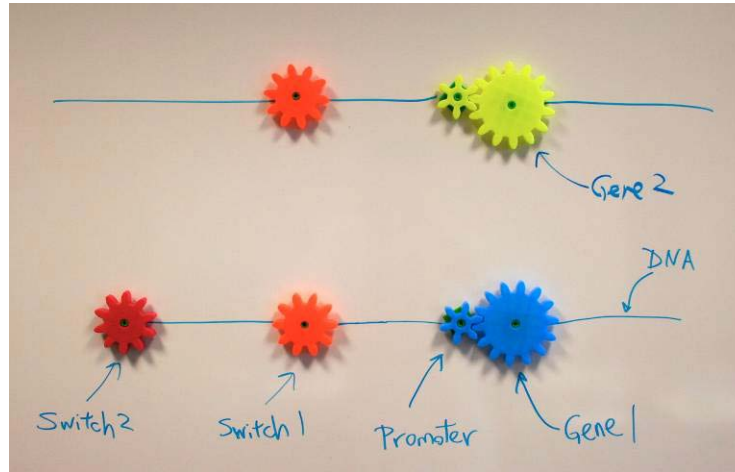
Below is a possible model that utilizes FridgeGears. There are several other ways this can be done. The below is just to provide you with one possible scenario. As long as student models represent the process and do not include bad science, they should be accepted.

What Gears Represent	Illustration	Description
<p>1. One or more large gears can represent the gene and a small gear the promoter.</p> <p>Students can draw the DNA that is not directly involved in this process.</p>		
<p>2. A medium size gear can represent a switch. It can be upstream or downstream from the gene.</p>		<p>The gene switch determines when and where the gene is turned on.</p>
<p>3. Use a small gear of a different color to represent a regulatory molecule</p>		

<p>4.</p>		<p>The regulatory molecule binds to the switch. If the regulatory molecule is not present in the cell, the gene is not activated.</p>
<p>5. Use the large motorized gear to represent the RNA polymerase.</p>		<p>The switch recruits RNA polymerase when the appropriate regulatory molecule binds to the switch.</p>
<p>6. When the motorized gear binds to the promoter, turn it on. The gears making up the gene will turn. This represents transcription. Use yarn to represent mRNA being synthesized.</p>		<p>The RNA polymerase lands on the promoter. This allows the gene to be expressed. The RNA polymerase makes mRNA for protein synthesis.</p>

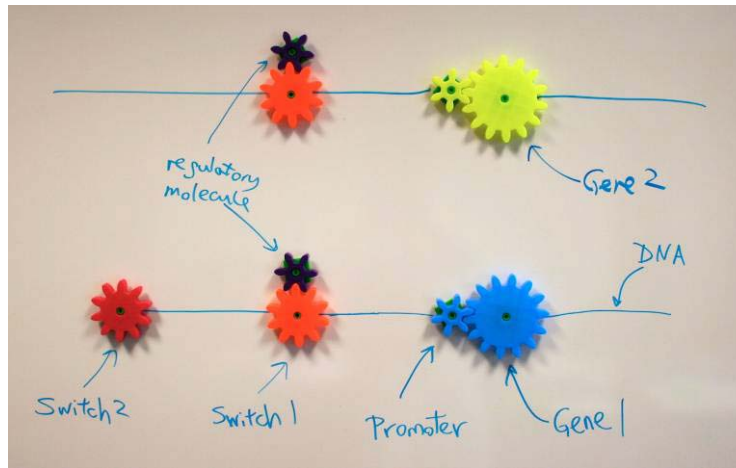
Extension: Two Genes Can Have Identical Switches

1. Both Gene 1 and Gene 2 have Switch 1. Switch 1 is represented by the same color and size gear for both genes. Gene 1 has an extra switch (Switch 2).



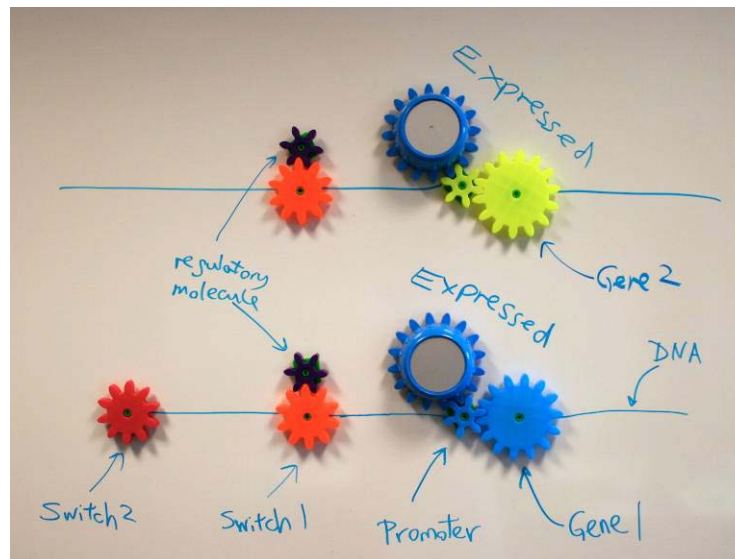
Here we are looking at part of a genome in the cell of a fruitfly.

2. The gear representing the regulatory molecules is the same color and size for both genes.



Now let's look inside a cell in the tail of the fruitfly. Two identical regulatory molecules can activate both Gene 1 and Gene 2. The regulatory molecules bind to the switches (Switch 1) at both loci.

3.



The switches recruit RNA polymerase to the promoters and both Gene 1 and Gene 2 are expressed in this tail cell.

4.		<p>Now let's look inside a cell in the head of the fruitfly. In this cell, a different regulatory molecule is present and binds to the head switch (Switch 2). The switch recruits RNA polymerase to the promoter and Gene 1 is expressed. Gene 2 does not have a head switch and is not expressed.</p>
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Extension: Homologous Genes in Two Species

1.		<p>This illustrates homologous genes (Paintbrush) in two closely related species...such as species of fruit flies. Both species have a tail switch. Only Species 2 has a wing switch.</p>
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2.		<p>The "tail" regulatory molecules bind to the tail switches. It is the same switch, regulatory molecule, and gene in both species.</p>
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3.		<p>RNA polymerase is recruited to the promoters and the Paintbrush gene is expressed in both species.</p>
4.		<p>The regulatory molecule that binds to the wing switch is present in both species. However, only Species 2 has the wing switch. Therefore, the Paintbrush gene is only expressed in the wing in Species 2.</p>

Correlation to National Science Education Standards

Unifying Concepts and Processes

- Systems, order, and organization
- Evidence, models, and explanation
- Evolution and equilibrium
- Form and function

Content Standard A: Science as Inquiry

- Identify questions and concepts that guide scientific investigations
- Formulate and revise scientific explanations and models using logic and evidence
- Recognize and analyze alternative explanations and models
- Communicate and defend a scientific argument

Content Standard C: Life Science

- The cell
- Molecular basis of heredity
- Biological evolution
- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

Content Standard D: Earth and Space Science

- Earth's history

Content Standard G: History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge

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