Synthetic Biology Lesson Pack
Lessons for students aged 11 – 16

Alexis Moschopoulos[1], Aseda Addai[2], Harry Akligoh[3], Hans Pfalzgraf[4]
Sabrina Gonzalez-Jorge[5], and Anna Sera Lowe[6]

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Affiliations:

1. Grobotic Systems Ltd, UK
2. Prac-Science Lab, Kumasi Hive, GH
3. Kumasi Hive, GH
4. School of Biological Sciences, University of East Anglia, UK
5. Department of Plant Sciences, University of Cambridge, UK
6. Io Innovations UK and Kumasi Hive, GH

Corresponding authors:

alexis@groboticsystems.com (AM); aseda.oad@gmail.com (AA); harryakligoh@gmail.com (HA); H.Pfalzgraf@uea.ac.uk (HP); sg794@cam.ac.uk (SGJ) and anna@ioinnovations.com (ASL)

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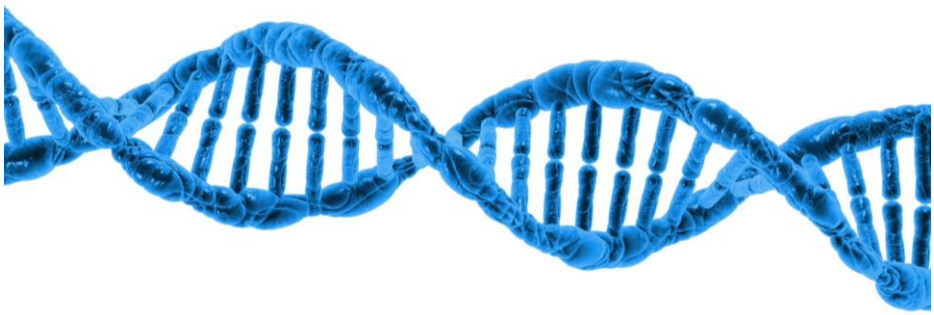


Lesson objectives:

- Why are **genes** important?
- How does **DNA** store **information**?
- How much information is in your DNA?

Questions:

What is a gene?

_____

What sort of things have genes?

_____

What can genes do?

_____

What are traits?

_____

Activity 1 – Trait Bingo

B	I	N	G	O
Aunt	I have allergies	Straight hairline	Freckles	Mother
I cross my right thumb over my left when I clasp my hands	Can not taste PTC	Curly hair	Neighbor can not taste PTC	Straight hair
Father	Grandmother	Free	Attached earlobes	Dimples
I have a different trait than the person sitting next to me	Cleft chin	Can taste PTC	Uncle	Can not roll tongue
Detached earlobes	Shared trait - Left	Trait in common - Right	I cross my left thumb over my right when I clasp my hands	Least common trait

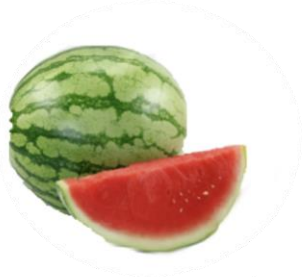
Trait Bingo by Molly Malone and Harmony Starr © 2006 University of Utah
Downloaded at: http://teach.genetics.utah.edu/content/heredity/files/Traits-Bingo.pdf

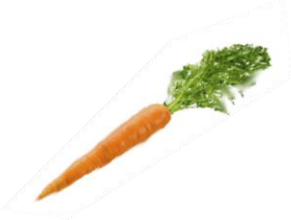
Activity 2 – What kind of traits do genes control in plants?

Most modern fruit, grains and vegetables have been selected, first by farmers and more recently by plant breeders.

Identify the ancient plant by drawing a line to its modern relative:







Questions:

What sort of traits did farmers and breeders select for?

_____

Can you think of other vegetables, fruits or grains and their wild relatives?

_____

Activity 3 – DNA and genes as letters and language.

We have seen that there are measurable differences in traits that are controlled by genes in a small human population (this class). Looking at modern fruit and vegetables and their wild relatives, we can see that genes can also control how large, tasty and healthy our food is.

But how do genes work?

One way to understand DNA and genes is to use the analogy of DNA as a language.

Find and circle the English words in this sequence of letters:

...KGHOWCKLGHDGWTXHGHXKLMNBPVOMANYGHQWORDSLKDQXPGH
DSWTLKJNCANWMDSWNNBCGIPLJMRWCOLPWERBCJKMLPOLIYOUKH
FIKFRLFINDWNSWCMINKLQGHXBKWKEGTHISPLQZXCNMPVBNMWDF
GLQPSEQUENCELPJGLXMQTHWXBNVCDOFPLNMTHDFLETTERSMVPL
RFGHZMQKLFGDYJKS...

Questions:

Why can you read these words?

_____
_____
_____
_____

What kind of meaning do words carry?

_____
_____
_____
_____

Here is the same sequence of English letters with the words highlighted:

...KG**HOW**CKLGHDGWTXHGHXKLMNBPVO**MANY**GHQ**WORDS**LKDQXPGH
DSWTLKJN**CAN**WMDSWNNBCGIPLJMRWCOLPWERBCJKMLPOLI**YOU**KH
FIKFRL**FIND**WNSWCM**IN**KLQGHXBKWKEG**THIS**PLQZXCNMPVBNMWDF
GLQP**SEQUENCE**LPJGLXMQTHWXBNVCD**OF**PLNMTHDF**LETTERS**MVPL
RFGHZMQKLFGDYJKS...

We can read the English words in the sequence of letters above, because when letters are put together in a particular order they carry meaning.

The English alphabet has 26 letters, and all English words are made up of these letters.

DNA has 4 letters: **A**, **T**, **C** and **G**. All of life is made up of these 4 letters!

Now, look the following **sequence** of DNA letters. Can you find the genes?

...CTGACGCATAATGTTCCTAATTAGGGGCAGACGATTTCTTGAACTGT
ACTGACTAACATAGAGTTGAAAACAAACACAGCTAGTATCCAACCTTAGA
CGACTTCGCCATGTCGTCGTCCACCAAGAGGCTGGTTCGTCCTCACCATC
TCGCGAAACCATTGCTTACCATGCTGCACATCTTTCGGTCGTGGATCACC
GGCACAGATTGCTGCCACTGGGACGGCGTCGACTGCGGTGGCGGCTAAGA
CATCAGCCCTGCACTCGT...

Here is the same sequence of DNA letters with two types of DNA coloured in:

...CTGACGCATAATG**TTCCTAATTAGGGGCAGACGATTTCTTGAACTGT**
ACTGACTAACATAGAGTTGAAAACAAACACAGCTAGTATCCAACCTTAGA
CGACTTCGCCATGTCGTCGTCCACCAAGAGGCTGGTTCGTCCTCACCATC
TCGCGAAACCATTGCTTACCATGCTGCACATCTTTCGGTCGTGGATCACC
GGCACAGATTGCTGCCACTGGGACGGCGTCGACTGCGGTGGCGGCTAAGA
CATCAGCCCTGCACTCGT...

The first of the coloured sequences **TTCCT...** is called a **promoter sequence.** The promoter sequence is a piece of DNA that acts like a **switch**, telling the **cell** where and when to turn the gene on. This type of DNA sequence can be described as being **non-coding**. It carries information, but it is not turned into a **protein**.

The next piece of coloured sequence **ATGTC...** is called a **coding sequence.** Coding sequence is another way to call the DNA sequence that is turned into a protein.

Activity 4 – How much information does DNA store?

How much DNA do you have in your body? If you took the DNA from each of your cells, how long would the DNA from your body stretch if it was laid out end-to-end?

The human body contains approximately 15,000,000,000,000 (15 trillion) cells that contain DNA. The DNA from *one of your cells* would stretch 2 meters if you uncoiled it and lay it end-to-end.

How far would all of the DNA in your body go if you lined it up?

_____

_____

Each human cell that contains DNA carries about 3,000,000,000 (3 billion) DNA letters. The average book has 500,000 letters.

How many books would all the DNA in your body fill?

_____

_____

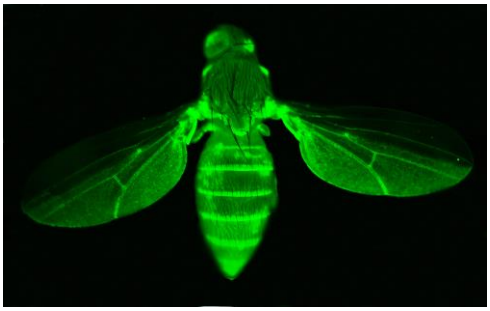
Each of your cells in your body has the same DNA, but you have hundreds of different types of cells, and all of your billions of cells are doing different things at the same time. Like an instruction book with many chapters, some cells read and follow Chapter 1, while other cells read and follow Chapters 2 or 3.

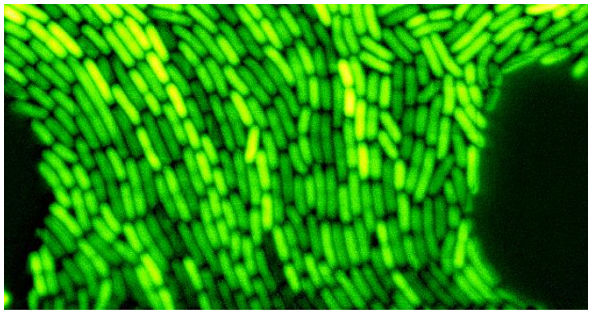
The DNA language is **universal** – all living things have DNA, and something written in DNA in one organism can be read by a totally different organism. For example, we can take **green fluorescent protein** (GFP) from jellyfish (left) and put it into bacteria, plants or animals.

Activity 5 Identify the genetically modified organism

The GFP gene from **jellyfish** can be copied and inserted into other organisms, due to the universality of DNA. Identify the organisms below from the list:

Fruit fly
Mouse
Plant
Bacteria
Rat
Tobacco

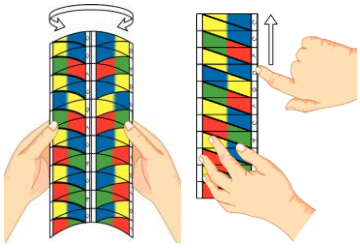




ORIGAMI DNA

Folding instructions

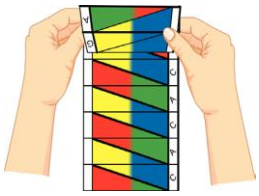
Note: All folds should have a thin line on the inside and a thick line on the outside.



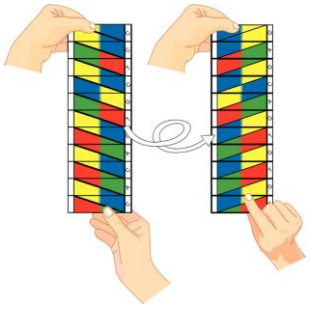
1 Fold in half lengthwise. Make all creases as firm as possible (use your fingernail!)

2 Hold the paper so that the thick lines are diagonal and the thin lines are horizontal. Fold the top segment down and then unfold.

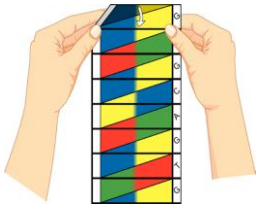
3 Fold the top two segments down along the next horizontal line. Unfold.



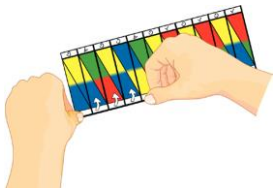
4 Repeat for all segments.



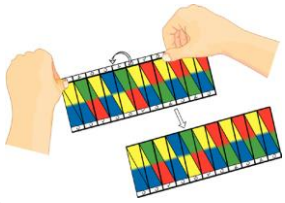
5 Turn the paper over.



6 Fold along the first diagonal line. Unfold and fold along the second diagonal line. Repeat for all diagonal lines.

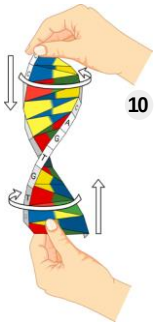


7 Fold the white edge without letters up.



8 Fold the other edge away from you. Partly unfold both edges.

9 You can now see how the model is starting to twist.



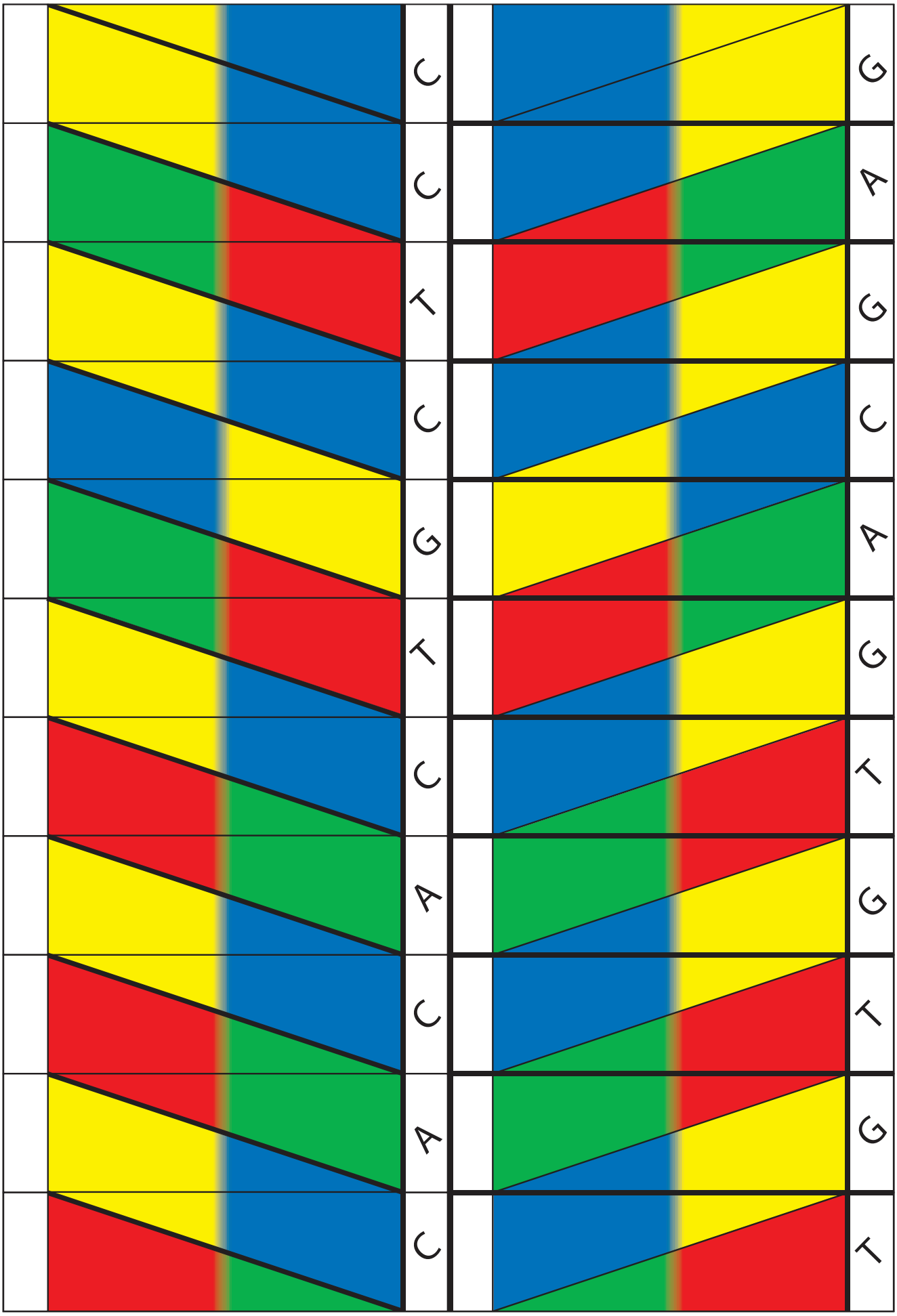
10 Twist and turn the paper while pushing the ends towards each other.

Be brave!

11 Now let go!

12 Admire your completed DNA double helix!

Only another 2,999,999,989 (or so) more to complete your whole genome!


C
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T

Lesson 2: Observing cells under a microscope

Lesson Objectives:

- Learn how to follow a scientific **protocol**
- Differentiate between plant and animal cells under the microscope.
- Understand that the building block of life is the cell.
- Learn the parts of the microscope and how it functions.
- Identify other types of microscopes.

A scientific protocol is a set of instructions on how to carry out a procedure or experiment. It is like a recipe, but instead for preparing food, it is for preparing or carrying out an experiment. Like a recipe, it has several sections. First, a protocol should have a purpose, so that the reader knows what the protocol does. Next, a protocol should have a list of materials or tools that the user needs in order to carry out the protocol. Finally, a protocol should have a method, or series of steps, that the user carries out in order to complete the experiment.

Purpose:
This protocol allows students to observe plant and animal cells.

Materials:
Microscope (can use a Waterscope, www.waterscope.org/3d-printing/ or other type of microscope)
Microscope slide
Cover slip (clear tape can be used)
Sample cells (plant leaf and/or cheek cell suspension from rinsing your mouth with water)
Stain, such as iodine or toluidine blue

Method:

1. Prepare a microscope slide by using the following approach
    a. Gargle some water in your mouth and pour it in a clean disposal cup to obtain your cheek cells, or
    b. mash some plant leaves in water to obtain a plant leave/water mixture.
    c. Place a drop of either the cheek cell or plant leaf suspension on the microscope.
    d. Place a drop of stain, such as iodine or toluidine blue.
    e. Using a cello tape, cover the drop of cell suspension.
2. Place the slide you prepared on the microscope stage and hold it in place with the microscope stage.
3. View the cells using the focus adjusters.

Questions:

Can you see the plant cell wall?
Can you see the nucleus?
What other structures can you see?
Are plant and animal cells the same size?

Lesson 3: Extracting DNA from fruit

Lesson objectives:

- Learn how to follow a scientific protocol
- Learn about a **hypothesis**

We have learned that all living things have DNA. For this experiment, we want to prove this idea by formulating and testing a **hypothesis**. The hypothesis is that bananas and mangos both have DNA. To test the hypothesis, we will extract DNA from a banana and a mango.

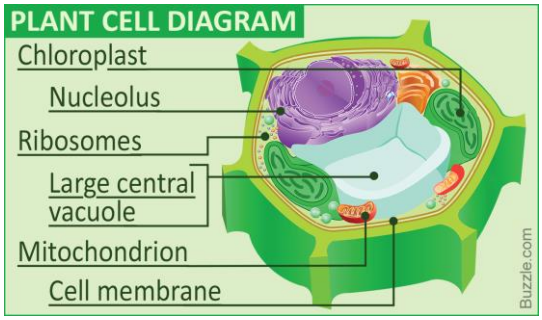
DNA Extraction Protocol

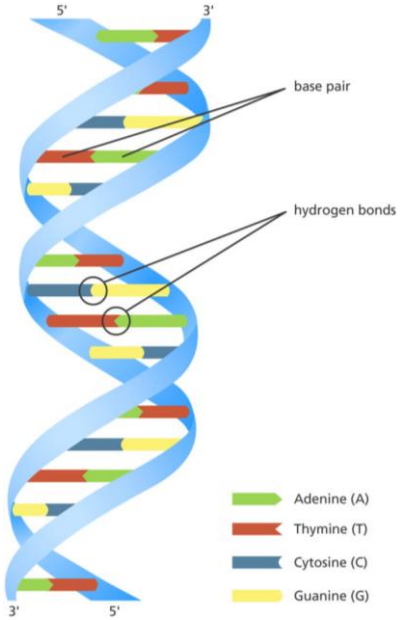
Purpose:

This protocol allows the user to extract DNA from fruit using common household chemicals and equipment.

Materials:

Clear plastic cups
Plastic bags
Water
Detergent powder
Table salt
Tissues
Handkerchief (optional)
Ice-cold isopropanol
Toothpick
Spoon





This diagram shows the DNA double helix with the four DNA letters, A, T, C and G.

Method:

1. Prepare the DNA extraction solution:
    a. Add 1 teaspoon detergent powder to a plastic cup.
    b. Add ½ a teaspoon salt to the same cup.
    c. Fill the cup half-way with water.
    d. Gently stir the solution to dissolve the detergent powder and salt.
2. Put a piece of fruit into a double plastic bag.
3. Gently squeeze the fruit until it is a fine mash.
4. Pour half of the cup of DNA extraction solution into the double plastic bag.
5. Gently squeeze the fruit and extraction solution, making sure to mix it very well.
6. Let the DNA extraction solution + fruit mixture sit for several minutes.
7. Prepare the filter by placing one tissue over the mouth of the cup.
    a. Optional: place a handkerchief beneath the tissue.
8. Gently pour the DNA extraction solution + fruit mixture into the filter. Make sure that only filtered liquid enters the cup.
9. Once the DNA extraction solution + fruit mixture has been filtered, carefully remove the filter from the mouth of the cup.
10. Gently add ice-cold isopropanol to the filtered solution. DNA should precipitate into the solution as a white, stringy or fluffy substance.

Lesson 4: Grow your own microbes part 1

Lesson Objectives:

- Learn how to follow a scientific protocol
- Learn about a hypothesis
- Learn about collecting and analysing data
- Learn about microbes and sanitation

Purpose:

This protocol allows the student to test the effect of sterilisation liquid on the presence of microbes on student's skin. We have prepared petri dishes with sterilised nutrient agar, a gel that contains food that makes it easy for microbes to grow.

Hypothesis:

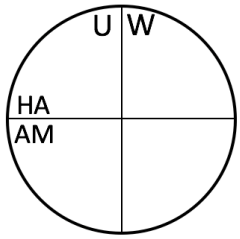
Sterilising gel is an effective way of reducing microbes on our skin.

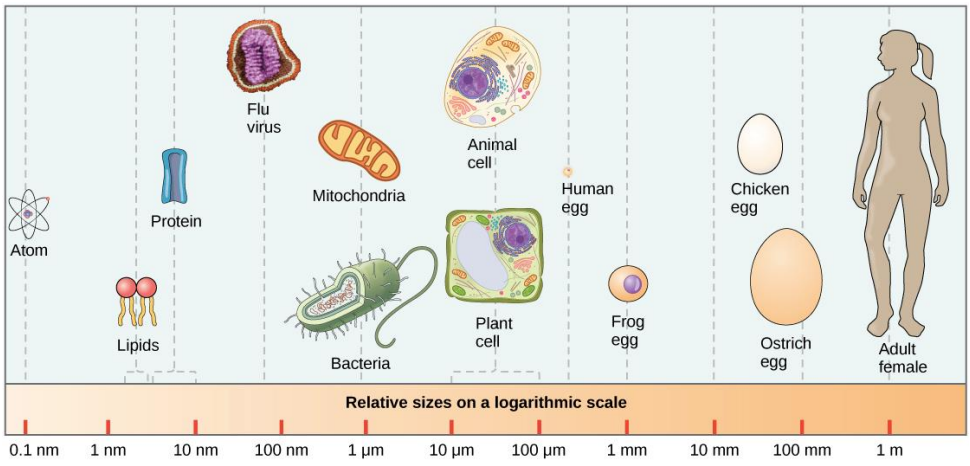
Materials:

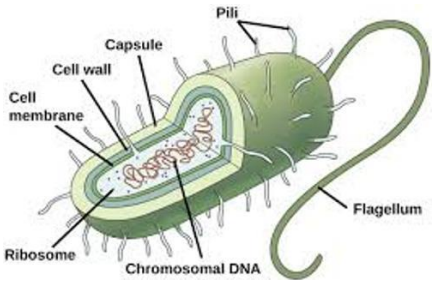
Petri dishes containing nutrient agar, Pen, Sterilising gel

Method:

1. Label the bottom of the petri dish (the dish that contains the agar) to split into 4 equal parts, by drawing 2 intersecting lines, as shown in the diagram:
    a. Optional: if you are three students, split the dish into 6 equal parts.
2. Label the left half with a U for unwashed, and the right half with a W for washed.
3. Label the top half with the initials of one student, and the bottom half with the initials of the second student in the pair.
4. Quickly and gently open the petri dish, and taking your two **unwashed** fingers touch the part of the dish labelled **U** and your initials. Quickly close the dish again.
5. Rub the sterilisation liquid between your fingers. Let it dry, and do not touch anything else while it dries.
6. Quickly and gently open the petri dish, and taking your now **washed** fingers touch the part of the dish labelled **W** and your initials. Quickly close the dish again.
7. Repeat again with your partner.
8. Store the petri dishes over night at room temperature.
9. The next day, observe the differences in microbe growth between the unwashed and washed sections of the petri dish.







Lesson 5: Grow your own microbes part 2

Lesson Objectives:

- Learn how to follow a scientific protocol
- Learn about a hypothesis
- Learn about collecting and analysing data
- Learn about microbes and sanitation

In the last lesson, we tested the hypothesis that using sterilising gel is an effective way to clean our skin. In this lesson, observe the outcome of our experiment to see if our hypothesis can be supported by the evidence.

Your petri dishes will have been left to grow overnight. **Collect your petri dishes, but make sure not to open them. They may contain microbes that are harmful to your health.**

Microbe counting protocol:

Purpose:
The purpose of this protocol is to count or measure the amount of microbial growth on the petri dish that has been touched by washed and unwashed fingers. Using a ruler, you can measure the area of microbe growth in the two treatments. You can also count the number of small dots of microbes, also called colonies.

Materials:
Petri dishes left to grow overnight
Ruler
Notebook or somewhere to write results

Method:

1. Using a ruler, measure the area of microbe growth from the washed and the unwashed areas of your petri dish.
    a. There might be a number of dots or colonies. You can measure each one. Add them all together to get an estimate of the area of microbes in each treatment.
2. Count the number of dots or colonies from each treatment.

Questions:

Which treatment resulted in the greatest number of microbes on the petri dish?
Does measuring the area of microbe growth or counting the number of dots or colonies of microbes result in a more accurate result?
Was your hypothesis supported by your experimental evidence?

Lesson 6: DNA and synthetic biology

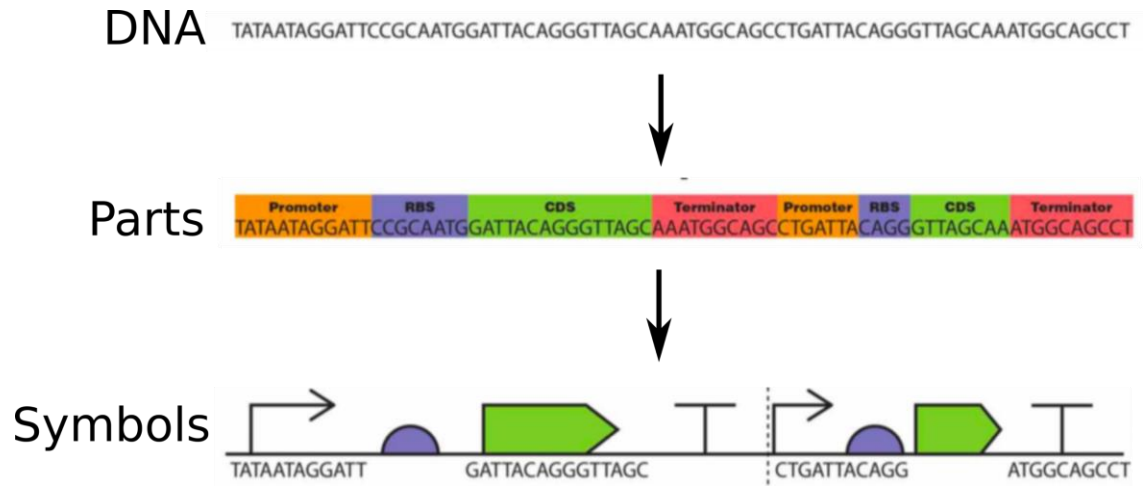
Credit: goo.gl/eV7n8N
L Zong and Y Liang

Lesson Objectives:

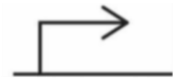
- How can we understand DNA as a combination of parts?
- How can we use symbols to describe electrical and genetic circuits?
- What kind of genetic machines can we make using synthetic biology?

DNA is a chemical that is used to store information. Some DNA parts or “words” that code for **proteins** are called **genes**. Other DNA parts carry other types of information, like telling the **cell** where and when to turn the gene on or off.

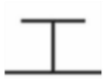
We can split DNA into component pieces, like splitting a sentence into words. Some words make proteins, while other words tell the cell when to make the protein, or how much of the protein to make.



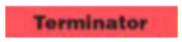
Activity 1 – Match the DNA part to the symbol



CDS (coding sequence): This sequence codes for a protein.



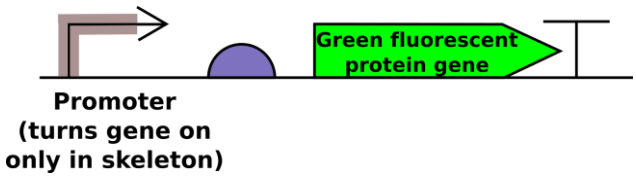
Promoter: The promoter sequence is like a switch, which tells the cell when and where to turn the gene on or off.



Terminator: This sequence tells the cell where to stop reading the gene, like a full stop at end of a sentence.

RBS (ribosome binding site): This sequence controls how much or how little the gene is turned on.

In the picture below, scientists have attached a promoter from a gene that is turned on in the skeleton to the GFP gene. Using the same symbols above, the genetic circuit would look like this:



The genetic circuit was then put into mice using genetic engineering. The resulting mice looked like this:

The emerging field of **synthetic biology** can be defined as ***the application of engineering principles to biological systems.*** Three important concepts in synthetic biology are discussed below. Can you think of an example of each of these concepts?

Deconstruction: Breaking down a system into smaller component parts that are easy to understand and to use.

Example:

_____

Abstraction: Simplifying a part or component to only the relevant information.

Example:

_____

Standardisation: Agreeing on technical standards to increase the compatibility and reusability of parts.

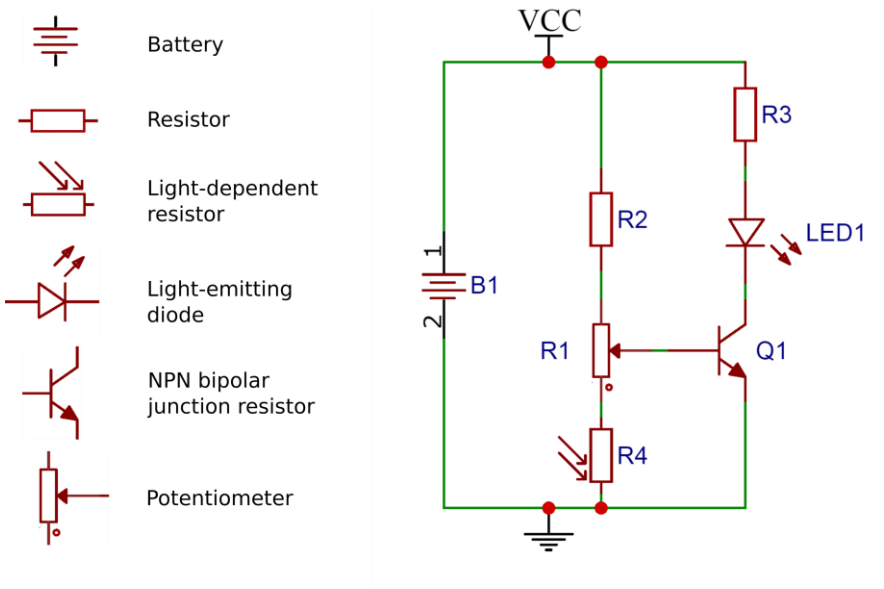
Example:

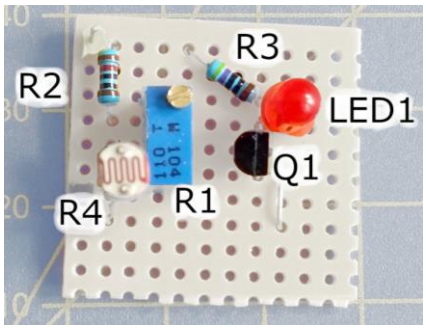
_____

Activity 2 How does an electrical circuit work?

Electrical engineering principles in particular are very useful when trying to understand synthetic biology. An electrical circuit can be **deconstructed** into component parts. We can use a part if we know the **abstract** function of the part, without having to know all the details of how it works. Finally, electrical parts come in **standardised** forms. This means that, for example, we can interchange differently rated resistors in the same place in a circuit.

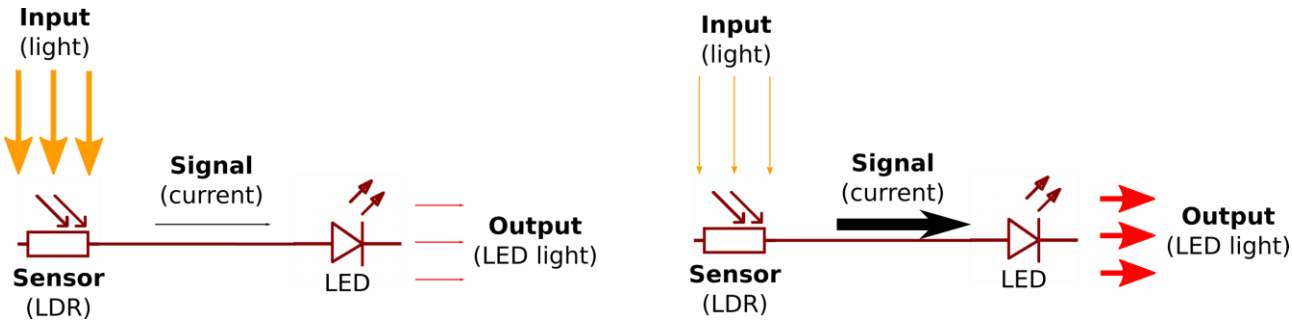
Electrical engineers use symbols to describe electrical circuits and components. On the left of the diagram below there is a list of symbols and their meanings. In the middle, there is a logical diagram of an electrical circuit. On the right is a photograph of the circuit board described in the diagram, with the components labelled on the photograph.



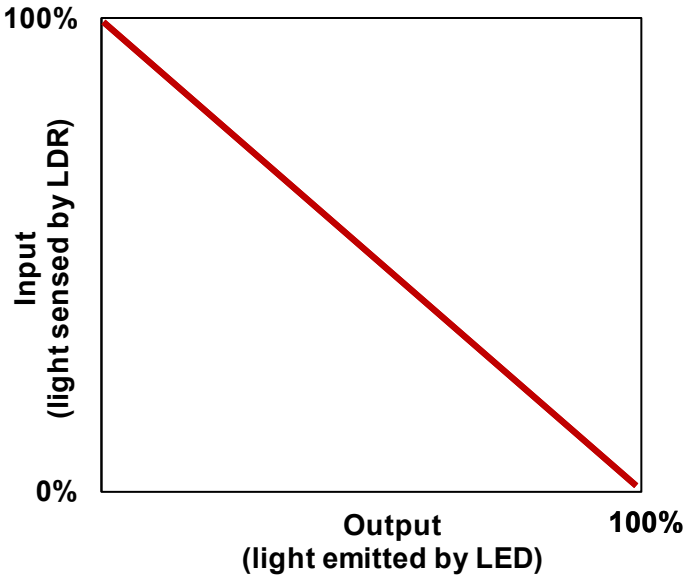


Credit: Richard Banks

We can simplify or abstract the circuit even more. Some components, like R2 and R3, are necessary to make the LED function properly, but do not affect how the circuit as a whole senses and responds to light, so we can leave them out of the diagram. We can draw this abstract circuit in two states. On the left, the LDR senses a high input of light which sends the current to ground instead of to the LED, such that the LED does not emit. On the right, the LDR senses a very low input of light which leads to current passing through the LED, such that the LED emits light.



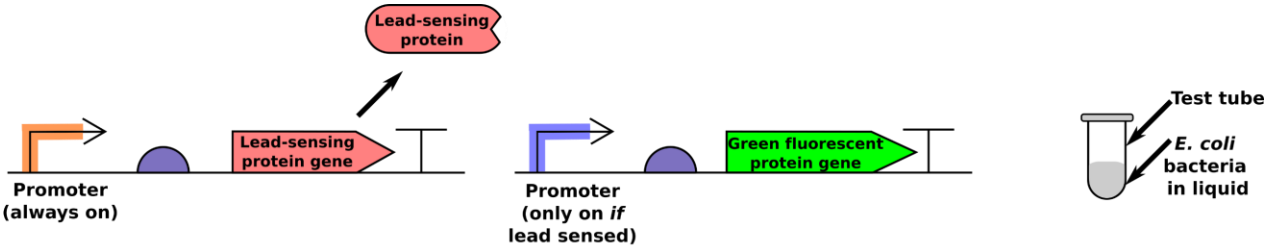
The ideas of deconstruction, abstraction and standardisation mean that we can take simple electronics components and build a complicated system that reacts and responds to external stimulation. The circuit represented in the diagram above responds to the amount of light hitting the light-dependent resistor by illuminating the light-emitting diode. It is a sensor that takes an input (light) and sends a signal (current) to respond with an output (LED light). We can plot the input and output of the system on a graph:

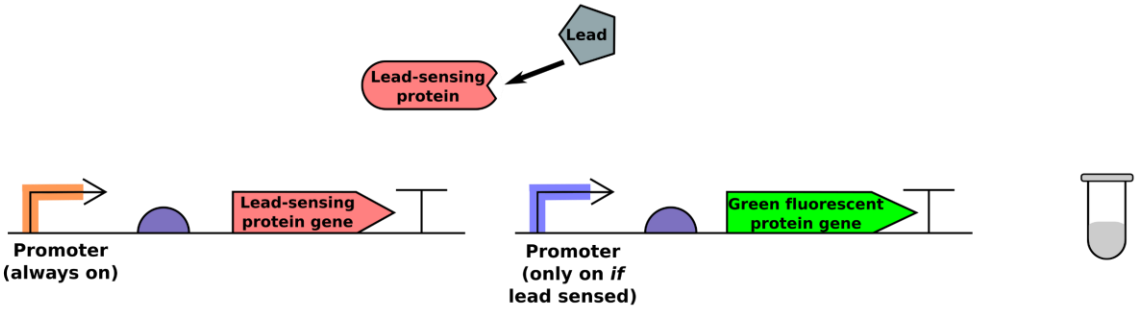


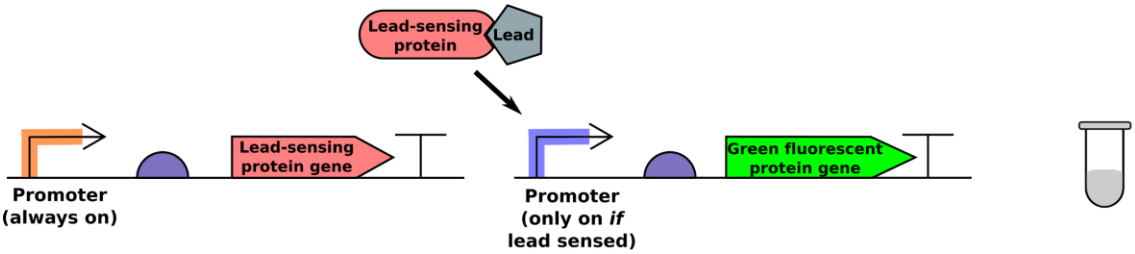
Importantly, the components used in this circuit can be used in other types of circuits. Similarly, once we have identified and characterised DNA parts from natural systems, we can use these parts to make new and different **genetic circuits**.

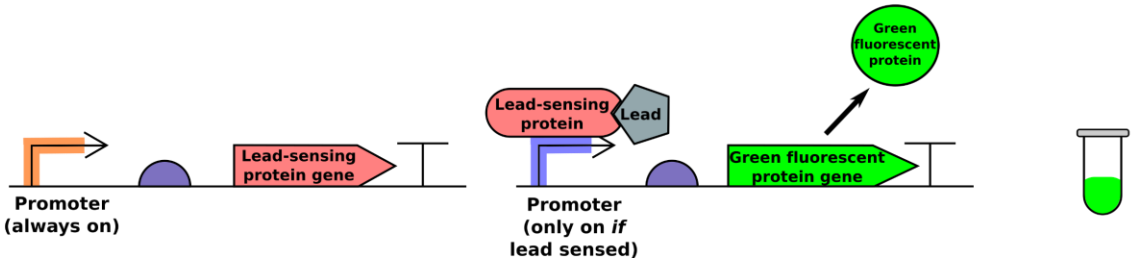
Using techniques of genetic modification, we can combine these new genetic circuits into different organisms. For example, we can put a new genetic circuit into a bacterium like *E. coli*. We can also put new genetic circuits into other single-celled organisms like yeast, or into complex multicellular organisms like plants and animals.

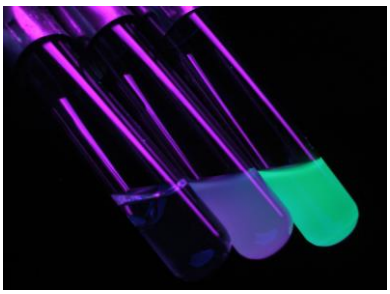
What sort of genetic circuits do people make? As part of an international competition on genetically modified organisms called iGEM, a team of students from a Taiwanese high school decided to make a biological circuit to be able to detect lead contamination in drinking water. This biological circuit was genetically modified into a common lab bacteria called *E. coli*. They used a number of standard DNA parts that other people had made, and were able to make some new parts specific to their project. Here is a diagram describing their genetic circuit, using the types of genetic symbols discussed above:


Lead-sensing protein
Lead-sensing protein gene
Promoter (always on)
Green fluorescent protein gene
Promoter (only on *if* lead sensed)
Test tube
E. coli bacteria in liquid

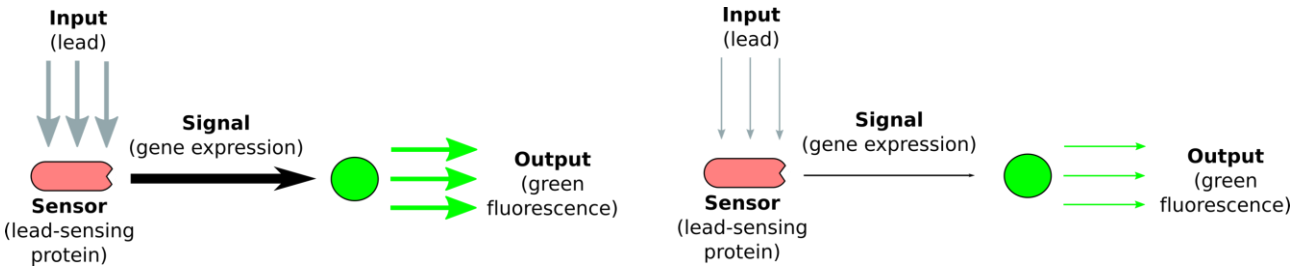

Lead
Lead-sensing protein
Lead-sensing protein gene
Promoter (always on)
Green fluorescent protein gene
Promoter (only on *if* lead sensed)


Lead-sensing protein
Lead
Lead-sensing protein gene
Promoter (always on)
Green fluorescent protein gene
Promoter (only on *if* lead sensed)

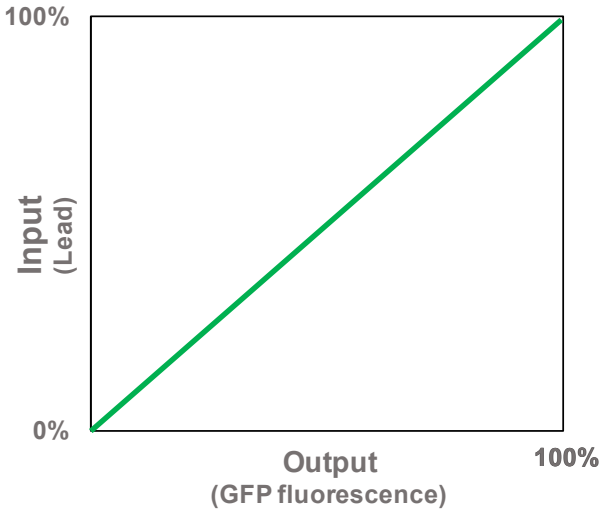

Green fluorescent protein
Lead-sensing protein
Lead
Lead-sensing protein gene
Promoter (always on)
Green fluorescent protein gene
Promoter (only on *if* lead sensed)



The genetic circuit senses an input (lead) through a sensor (lead-sensing protein) and sends a signal (gene expression) so that we observe an output (green fluorescence). As with the electrical circuit diagram, we can draw a simpler genetic circuit diagram:



We can also plot the input and output of the system on a graph, similar to when we plotted it for the electrical circuit:



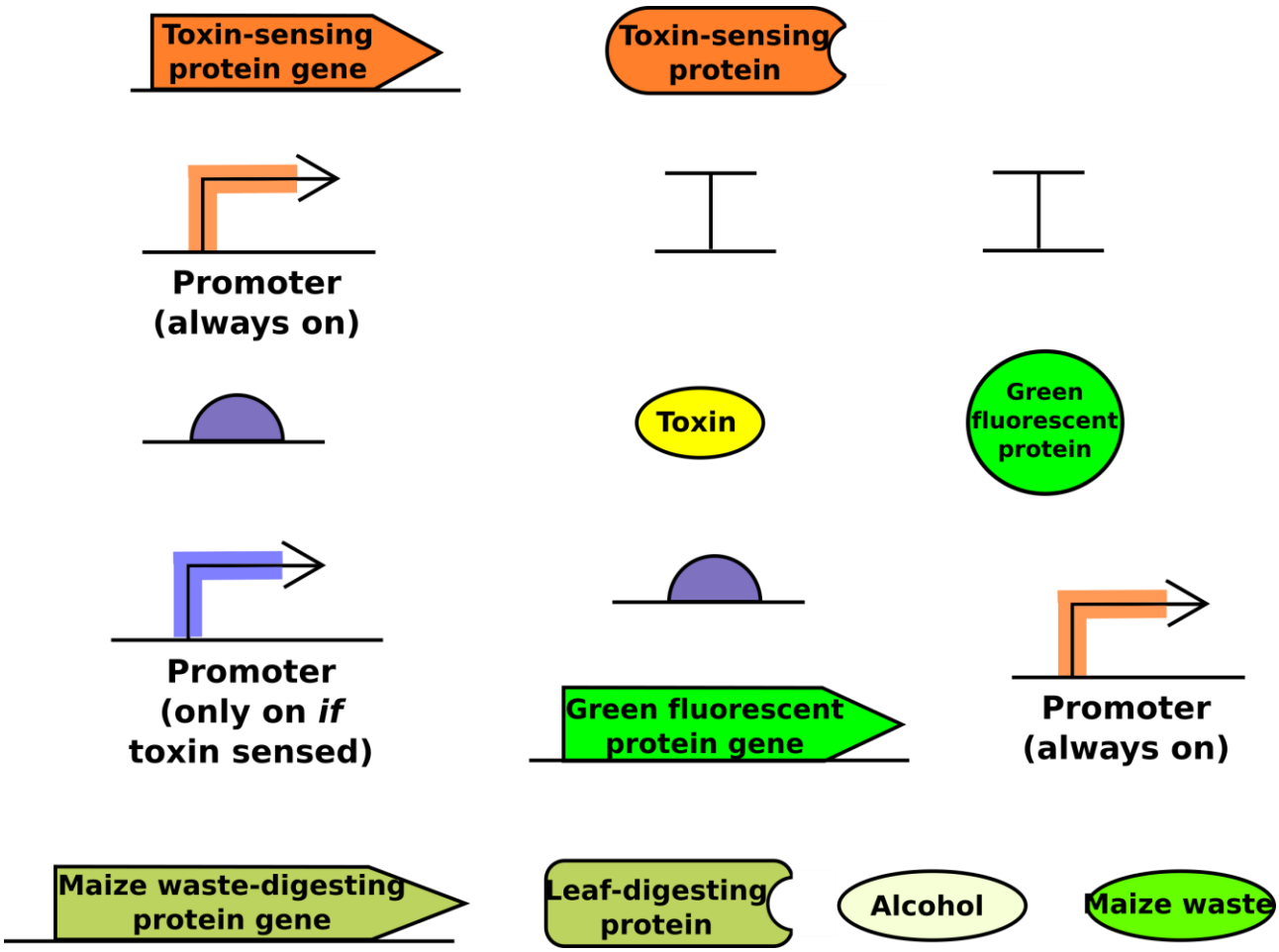
There are many different types of biological machines we can make with synthetic biology. The biological machine we can make above is a type of biosensor. We can also use DNA as information storage, like we use a hard drive to store data on a computer. We can also manufacture enzymes, colouring, flavours, or other types of additives for food or industry.

Activity 3: Make a genetic circuit

Toxins in foods can cause serious illness. Given a number of DNA parts, make a genetic circuit so that when your biological machine senses toxin, the green fluorescent protein lights up.

A second genetic circuit would allow you to produce alcohol for fuel from the waste parts of the maize plant like the stem, leaves and husk. How would that ciruit look?

Cut out the components of the genetic circuit below, and assemble it into the correct order.



Question:

What sort of problems in your community could you solve through the use of genetic circuits?

_____

Glossary

Term	Definition
abstraction	Simplifying an object or an idea to its most simple form.
amino acid	One of twenty nitrogen-containing organic molecules that make up proteins.
cell	The smallest structural and functional unit of an organism. Cells are enclosed with a membrane or a wall, and structures like the nucleus.
cloning	To cut and paste a gene or DNA sequence from one source of DNA into another. You clone a gene from one species and transform it into another.
coding sequence	The DNA sequence of a gene that directly encodes for a protein.
codon	A sequence of three DNA or RNA letters that code for a particular amino acid.
construct	A human-designed, circular piece of DNA propagated in bacteria, containing artificial genes or a combination of artificial genes. Also known as a plasmid or a vector.
deconstruction	Breaking down a complex system into small, simple parts.
DNA	Deoxyribonucleic acid. A self-replicating molecule made of four chemical letters (also known as bases or nucleotides) that carries genetic information.
double helix	A pair of intertwined parallel helices.
gene	A sequence of DNA letters that determine the amino acid sequence of a protein. A unit of heredity, that determines a particular trait.
gene product	The biochemical material, either RNA or protein, resulting from the expression of a gene.
genetic transformation	The process of moving a gene or genes from one organism to another. Another term for genetic engineering.
genetic circuit	A collection of DNA parts that form an interacting network of logical functions. Can be natural or synthetic.
genome	The complete set of genes or genetic information in a given organism.
genotype	The genetic sequence of an individual organism. Can mean the whole genome, or at a particular gene or piece of DNA.
green fluorescent protein	A gene from jellyfish that can be used to visualise gene expression in genetically modified bacteria, plants and animals. In this sense, it is used as a reporter gene.
hypothesis	A theory or idea for something that has not yet been proved. You can test a hypothesis using an appropriate experiment.
information	Something that is conveyed by a particular sequence of things, like DNA or English letters.
input	Energy or information entering a system.
molecule	A group of atoms bonded together.

mRNA	Type of RNA that conveys genetic information from the DNA to the ribosome for protein synthesis.
mutation	An alteration of DNA sequence, either through deletion or deletion, or other more complicated forms of rearrangement of DNA. A source of genetic variation.
non-coding sequence	A sequence of DNA that does not code for a protein. It can contain other types of information, like acting as a promoter or a ribosome binding site.
output	Energy or information leaving a system.
polymerase	A protein that strings together a sequence of DNA or RNA letters.
promoter	The DNA sequence around a gene that controls where, when and how strongly the gene is turned on or off.
protein	A biological molecule made up of amino acids that is an essential part of all living things. Can be structural, like muscle and hair, or carry out functions, like metabolism and DNA synthesis. Also known as a polypeptide.
reporter gene	A gene that enables the detection, visualisation or measurement of expression. Often attached to a promoter sequence, to study where that promoter is switched on.
ribosome	A large biological molecule made of RNA and proteins that converts RNA sequence into amino acid sequence. The site of protein synthesis.
RNA	Ribonucleic acid. This molecule acts as a messenger carrying instructions from DNA to form protein.
sequence	The precise order of DNA letters (for DNA sequence) or amino acids (for protein sequence).
standardisation	Process of developing standards-based and compatible technologies.
synthetic biology	The application of engineering principles to biological systems.
trait	A genetically determined characteristic, like height or (in plants) resistance to a particular disease.
transcription	The biochemical process of reading and converting DNA letters into RNA letters.
transcription factor	A protein that interacts with the promoter sequence of a gene to and controls the transcription of that gene, either by enhancing or supressing it.
transgenic	Containing a gene from another organism; synonymous with genetically modified.
translation	The biochemical process of reading and converting RNA letters into a sequence of amino acids, or protein.
universal	The DNA code is universal, meaning it is the same in all organisms, from bacteria to plants to humans.