A1 Synthetic Biology is ... applying Engineering Logic to Biology

Just as a car is made up of exact engineered parts, synthetic biologists treat living organisms as a set of complex biological 'parts'. These can be rearranged and modifed to make the organism perform new functions. A bit like Lego.

A2 Synthetic Biology is ... adapting what's evolved for new purposes

A team of women engineers at Volvo said cars have evolved with men in mind; let's redesign a car in ways women would find better. Synthetic biologists seek to take living organisms which have evolved, and redesign them for human purposes.

A3 Synthetic Biology is ... rearranging the 'parts' of Living Organisms

Synthetic biology seeks to take the basic parts that make up living organisms – genes, proteins, enzymes, cells etc. – and modify and recombine them to make organisms like bacteria do new functions that are useful to us.

A4 Synthetic Biology is ... bespoke 'tailoring' from parts of different organisms

As a clothes designer takes ideas and materials from many places, synthetic biologists select things organisms do – say the way one responds to light, or another makes a protein – and join them into a 'bespoke' organism they hope will do exactly what they want it to do.

A5 Is this a Biological Revolution?

Yes and no. Scientists have modified many living organisms, but synthetic biology could go much further, making more radical changes. But most of it is still in basic research. No one knows how much will really work, or get beyond just simple organisms.

A6 Synthetic Biology takes Genetic Modification much Further

Genetic modification (GM) adds, say, 2-3 extra genes to an organism, to perform one new function, like getting bacteria to make insulin. Synthetic biology would make multiple genetic changes to alter whole processes in the organism, like how it uses energy.

A7 Synthetic Biology: New or Old?

Since 1982 most insulin for diabetics is made in vats by *E.coli* bacteria, genetically modified with a human gene. Synthetic biology is building on such work, with the knowledge gained from 25 years of molecular biology.

A8 Expanding how we Use Micro-organisms Industrially

Micro-organisms are already used industrially, for example in making beer, foods, chemicals, drugs. A lot of synthetic biology is about what new things microbes could be made to do.

A9 BioBricks: Exchangeable Biological Parts

Just as machines are made of well known, standard, interchangeable parts, BioBricks are attempts to identify or construct exchangeable biological 'components', each with known properties, to build up into complex systems.

A10 BioBricks and Self-assembly Furniture?

BioBricks are like creating a set of parts to make up a flat-pack for self-assembly furniture. The parts are genes or molecules from biological cells, and the completed unit is a modified organism, or a module within it with some special function.

A11 Building a Toolkit of Useful Biological Parts

One BioBrick might be a biological sensor, taken from a bacterium which detects a toxin. It's joined to another 'brick' which sends a signal to warn a third brick, which is a switch, which turns on a last brick which triggers antibody production. And so on...

A12 Adding new letters to the DNA Code

The DNA 'code' is made of millions of combinations of 4 letters A,C,G, and T, which stand for 4 special molecules which are 'read' by enzymes. Scientists have now made synthetic molecules to add new 'letters' to the code, and have modified the enzymes to read them.

A13 Synthesising DNA Sequences

A key factor in making synthetic biology possible is that scientists can now make short pieces of the DNA code in their laboratories. These pieces can be joined up to create the complete DNA sequence of any organism, and even make new sequences.

A14 The Minimal Genome Project

If BioBricks try to build organisms in parts from the bottom up, the 'minimal genome' aims to do the opposite, 'stripping down' a bacterium to establish the smallest number of genes – maybe only 350 – needed for life... or at least bacterial life.

A15 Smallest Genome: a Backbone for Designer Microbes

Finding the simplest array of genes that support life could provide a backbone or 'chassis' of a simple designer bacterium, to which scientists could plug in biological parts (BioBricks) to perform a selected function.

A16 Genome Transplantation

Living organisms are made of cells, which are directed by the DNA inside them. One goal is to synthesise a semi-artificial genome from small DNA sections, and insert it into a living cell, so that the new genes take over the operation of the cell.

A17 Recoding Bacteria to Make New Chemicals

Bacteria like *E.coli* exist in many forms, some harmful some not. Scientists have 're-coded' some forms, replacing some genes by other ones, to produce useful materials that the bacteria do not make in their 'wild' forms, like spider silk protein or an anti-malarial drug.

A18 Creating Exchangeable Parts

Like Lego parts can fit different designs, it's hoped that parts developed for one synthetic biology application can be transferred to another.
So the module that makes the anti-malarial drug Artemisinin (story card 1) is being adapted to make biofuels.

A19 Where has Synthetic Biology got to so far?

A lot is hoped for but only a few applications are so far emerging. Mostly it's still quite basic research, to find out what works. Some of this is funded publicly, some by commercial companies, and some by the military.

A20 Innovation Depends on Understanding

The modifications attempted in synthetic biology will require a comprehensive understanding of genes, cell behaviour, and how these interact with each other. The aim is to make very precise changes which have predictable results.

A21 iGEM: The Best BioLego Competition!

The annual International Genetically Engineered Machine (iGEM) competition is a focus of innovation. Young bioengineers form university or national teams to devise ingenious projects to produce novel biological devices and parts.

A22 Environmental Clean-up

Synthetic biology offers a lot of potential for cleaning up the environment, like sensors to detect toxins, and perhaps modified bacteria that could remove the toxin and render it safe.

A23 Capturing Carbon Dioxide?

Absorbing carbon dioxide from the air is what plants do in photosynthesis. Could synthetic biology adapt the same biochemical mechanisms to remove CO_2 from power stations and cars?

A24 Spider Silk and Other Novel Materials

If we can find out how living organisms make natural materials like spider silk, and incorporate this into designer bacteria, we could make new strong and lightweight engineering materials with many uses.

A25 Reading Ancient DNA Codes

DNA is like code, which enzymes in the body can read and copy. Some enzymes have been modified to read ancient DNA sequences from archaeological and fossil specimens, like from 45,000 year-old cave bear bones.

A26 Synthetic Biology to Make Novel Crops

If the toolkits of synthetic biology work, they could be used to modify crops to overcome technical hurdles which held back some ambitious aims of GM crops – fixing nitrogen, making biofuels or pharmaceuticals in plants.

A27 Alternative Fuels: Hydrogen

Minimal genome bacteria and BioBrick components could be combined to make engineered bacteria able to break down water to make hydrogen as an alternative transport fuel, cheaply on a large scale.

A28 Alternative Fuels from Plant Wastes

Biofuel production from food crops is unsustainable. But cellulose in plant wastes would be an almost limitless source. It needs getting a lot of genes and enzymes to work together. Synthetic biology offers a real possibility to crack the problem.

A29 Biological Computing?

Another aim of synthetic biology is to construct biological parts into integrated molecular circuits that act like electronic circuits. A true biological computer is still a remote idea, however.

A30 Synthetic Biology and Nanobiotechnology

Genes are nano scale in size, so a lot of synthetic biology overlaps with nanotechnology. Indeed, it may provide key tools and devices for 'nano-medicine', say, to help control insulin for diabetics, or enable drugs to find diseased cells.

A31 Detecting Infection in Urinary Catheters

A biological sensor is being researched aiming for early detection of bacterial infections on catheters used in the urinary tracts of elderly patients.
A fluorescent protein, genetically engineered into the tiny device (outside the body), glows if it finds an infection.

A32 Smart Antibiotics and Vaccines

Bacteria adapt to antibiotics and become resistant to them. Biologically engineered antibiotics might be able to monitor how the bacteria are adapting, and modify their action accordingly. Smart vaccines might also adapt to protect us from a new strain of flu virus.