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COLLABORATION

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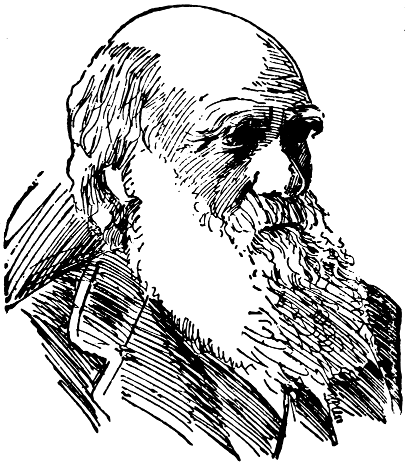
A quick guide to Synthetic biology.

For educators teaching school students.

What is life? How did it originate?

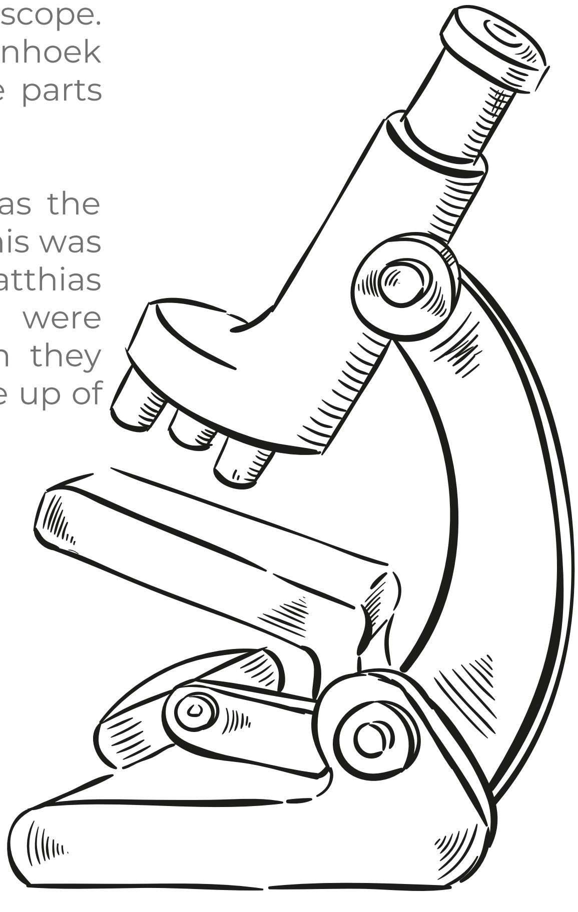


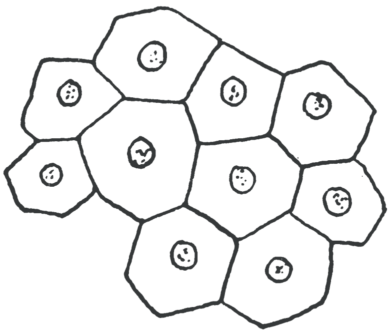
It is said that life on Earth originated about 4 billion years ago. There are two theories for this—Alexander Oparin's primordial soup, which is the hypothetical set of conditions present on the Earth around 4.0 to 3.7 billion years ago, and,

Charles Darwin's theory that life was conceived in a warm little pond with chemicals like ammonia, phosphorous, light and heat.

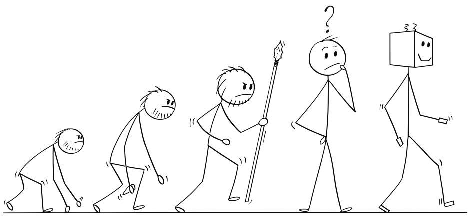
Cells are the basic structural unit of life, and cells arise from preexisting cells. In the 1600s, Zacharis Jansen invented the first compound microscope. After this, Antonie Philips van Leeuwenhoek discovered the cell structure and called the parts he saw animalcules.

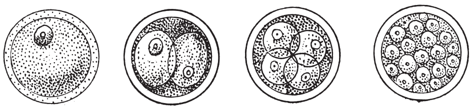
Robert Hooke coined the term 'cell' and was the first scientist to visualise a microorganism. This was the foundation of cell theory. Botanist Matthias Schleiden and zoologist Theodor Schwann were researching tissues in the late 1830s when they suggested that all living organisms are made up of one or more cells.





Survival of The Fittest





The Darwinian evolution theory stresses on natural selection. Organisms with genes better suited to the environment are selected for survival and pass them to the next generation.

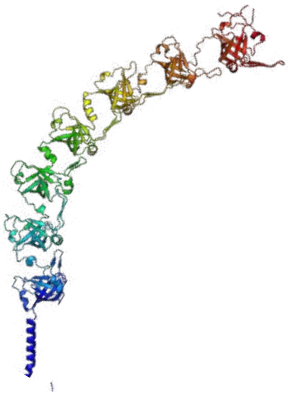
As a thought experiment, if you isolate a species, they compete for food and resources, and as generations proceed, they have genetic mutations. They give one individual an edge over the other, and if the individual survives, it passes that on to its offspring. The gene-centred view of evolution entails how adaptive evolution occurs through the survival of competing genes.

Q. Once honeybees sting, they die. How does this prove to be advantageous to the bee?

Different environments call for the selection of different traits. As a gene, you could have two ways of passing on features to your progeny. This can be done in two ways —direct fitness and indirect fitness.

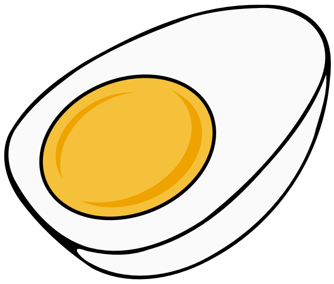
Here, bees use an indirect mechanism to allow their copies to spread. A single bee sacrifices its life to protect its hive, and thus, the other bees that carry similar genes survive and propagate. Intrinsically, this means that DNA and genetic information keeps the colony alive. Similarly, in African wild dogs, indirect fitness due to a challenging environment favours the survival of their nieces instead of producing offspring.

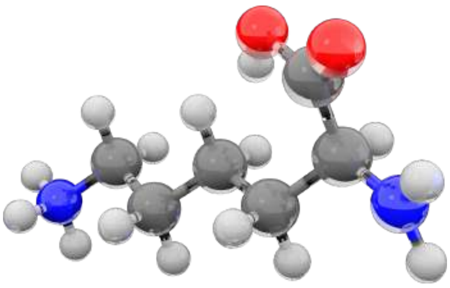
Proteins—what are they and how are they made?



All cells use proteins as their primary building blocks and operating molecules. All organisms create them by a similar two-step process known as protein synthesis, in which DNA is first transcribed into RNA and then translated into proteins.

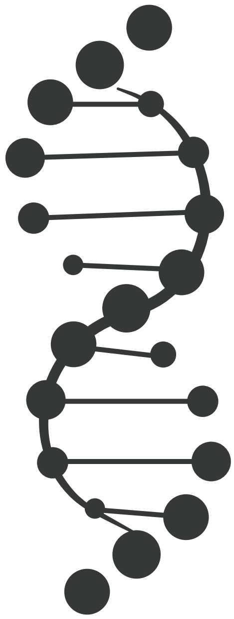
The primary "working molecules" in every organism are proteins. Proteins perform various functions, including oxygen transport, chemical catalysis, and infection defence. They are also essential components of organisms. They form the bulk of milk, wool, cartilage, and chromosomes, which contain and protect the DNA and insulate the nervous system's cells. In a nutshell, proteins are indispensable!





Numerous amino acids are linked end to end to form proteins. You might compare it to making origami with a very long, thin sheet of paper because the chains fold up to create three-dimensional molecules with intricate structures. Each protein's function is governed by its specific structure and the amino acids it contains.

Genes and DNA



Millions of little molecules known as bases build our DNA. There are four different chemical types—A, C, T, and G. A gene is a segment of DNA composed of a sequence combining As, Cs, Ts, and Gs.

Every cell in your body has around 20,000 genes owing to how minuscule they are. A few hundred bases to over a million bases make up a human gene, depending on the species. About 20,000 genes and 3,000,000,000 nucleotides are present in every individual. A genome is a collection of all of your genes and genetic building blocks.

What do your genes do?

Almost all of the cells in your body contain genes. Cells receive instructions to produce proteins from each gene. They use proteins for a variety of purposes, including producing the colour of your eyes, supplying energy to your muscles, and defending against bacterial invasion.

For instance, some cells employ genes that provide instructions to create keratin, a protein. Your body assembles keratin proteins to form structures like your hair and nails.

FUN FACTS!

Scientists say all the world's data can fit on a DNA hard drive the size of a teaspoon!

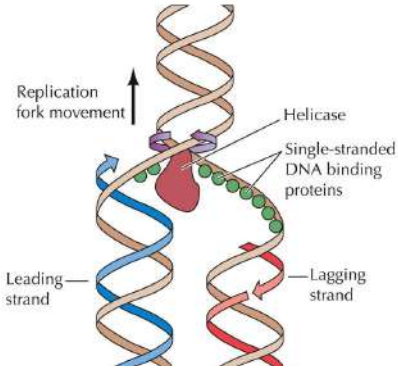
All the DNA in one cell combined would be nearly TWICE the diameter of the Solar System!

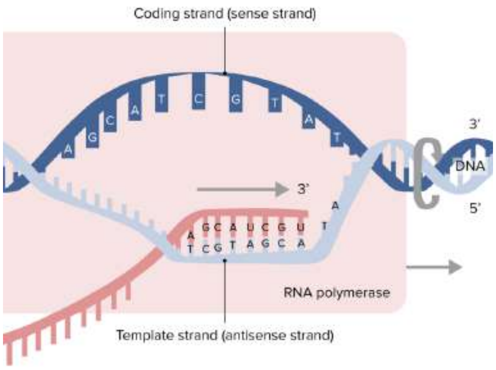
The Central Dogma of Life

The method by which DNA instructions are translated into useful products is known as the Central Dogma. Francis Crick, who discovered the structure of DNA, laid out the idea in 1958.

Replication

DNA replication is the biological process that creates two identical copies of DNA from a single original DNA molecule. All living things replicate their DNA, which is the primary mechanism for biological heredity.



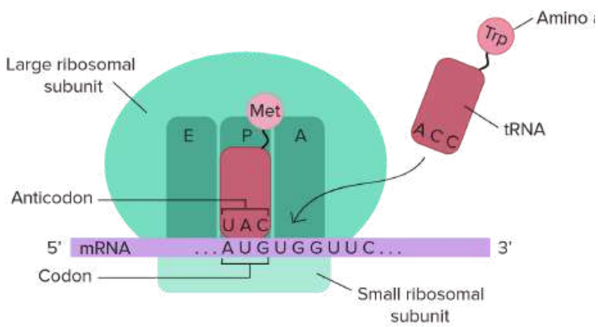


Transcription

Cellular structures recognise a gene's beginning and ending points and can read the DNA sequence in between (the order of A, C, G and T bases within the gene). The sequence of the gene itself is transcribed in a molecular message (an mRNA molecule). mRNA resembles a single-stranded molecule of DNA in most characteristics.

Translation

The mRNA molecule is taken up by a ribosome, which then begins to assemble a chain of amino acids (a protein) according to the exact instructions found in the mRNA. The sequence of three-base chunks, or codons, that make up the mRNA is "read" by the ribosome. Each codon instructs the machinery that creates proteins on what amino acid to add next.



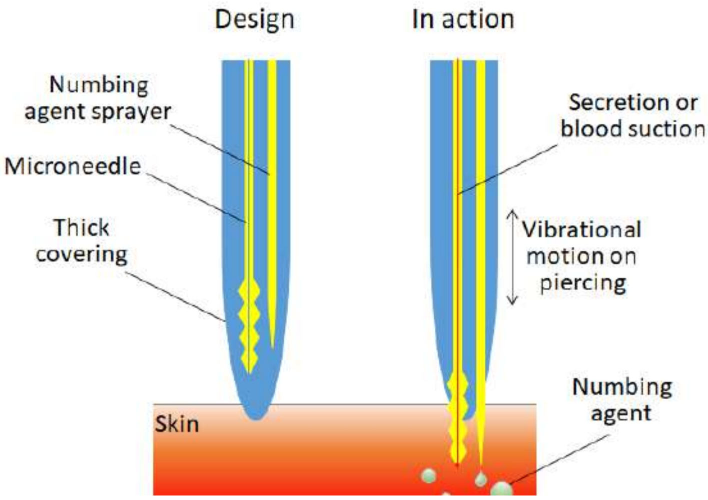
Ribosome: The process of making proteins in a cell takes place at an intercellular structure called a ribosome, which is composed of both RNA and protein.

Biomimetics: Exploring engineering solutions through nature

This process involves trying to mimic biological systems to solve a particular problem. On the left, you can see a windmill and some structures.

Whale fins inspired these structures to decrease the resistance and increase the efficiency by which the electricity is produced.

Another problem we see nowadays, especially in vaccines, is that people fear needles. To solve this problem, a technology for painless needles has been developed that mimics the ability of a mosquito to draw blood.



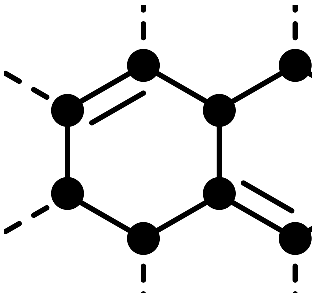
This process includes the use of two needles—one to numb the region by resembling mosquito saliva, while the other to inject the required medication or take blood samples.

Synthetic Biology

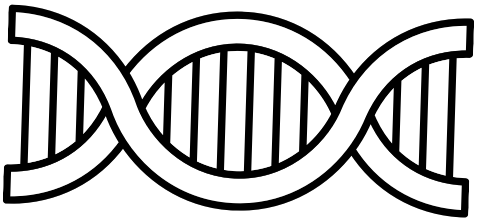
Synthetic biology is a field that enables us to engineer biological systems to get newer functionalities from them, consequently using these to solve practical problems. Before we go too deep into what it is, let's go back in time. The late 17th, 18th, and 19th centuries saw advances in understanding the basic concepts of biology and chemistry.

The mid-nineteenth century saw a revolution in synthetic chemistry, where organic molecules were being synthesised in labs and industries. This is a precursor to the biology-based version of synthesis in the 21st century—Synthetic biology.

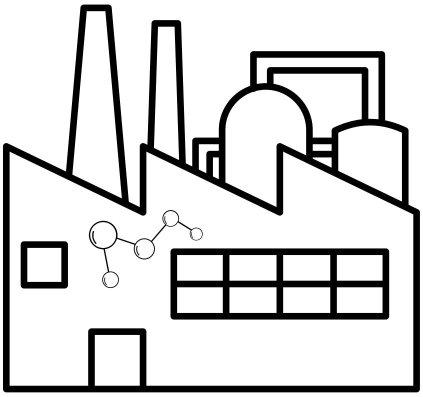
HISTORY



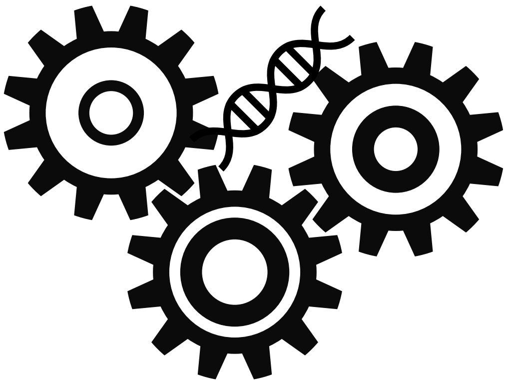
CHEMISTRY
Late 17th Century



BIOLOGY
18th-19th Century



SYNTHETIC CHEMISTRY
Mid-nineteenth century

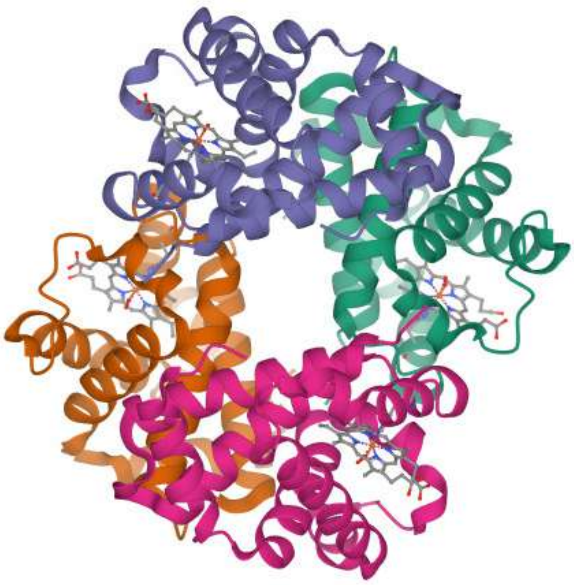


SYNTHETIC BIOLOGY
18th-19th Century

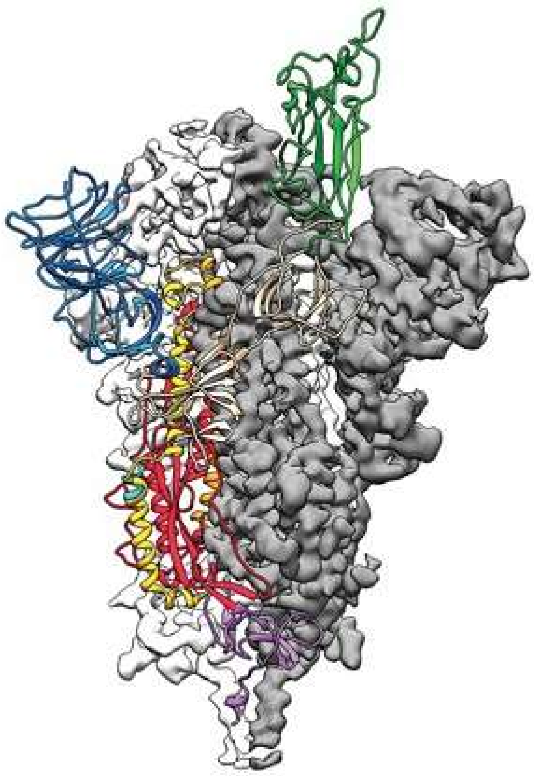
How does this work?

But how does it work? Just like computers have binary code as their foundation, biological systems have the genetic code, having four components or "bases"-A, T.G and C. Different combinations of these bases in the DNA code for different proteins that perform essential tasks,
How does this happen?

Let us say that we want to assemble a tool. We have a book with instructions to make a set of tools. We copy down the information needed to make this drill and then translate them into an actual assembly. DNA is our master manual. The information required to make one single protein is copied into an RNA, and a translation tool uses those instructions to assemble a protein.



Hemoglobin

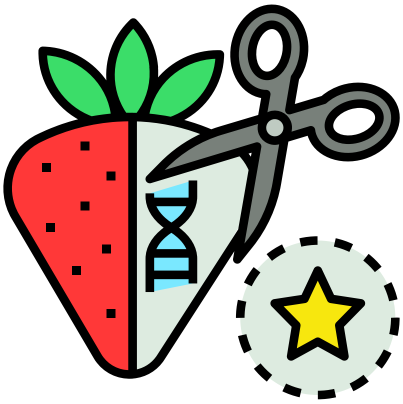


SARS-CoV-2 Spike Protein

In short, the information you read will determine the structure of the tool you make, which would also change its function. The same is true for proteins. On the left, we have haemoglobin. Its structure ensures that it can bind to 02 and transport it. The protein on the right is the spike protein of the COVID-19 virus.

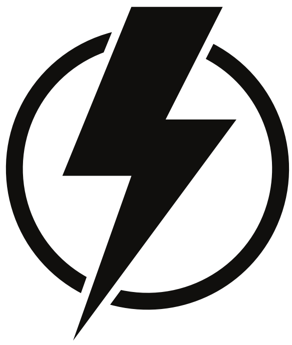
DESIGN-BUILD-TEST-LEARN!

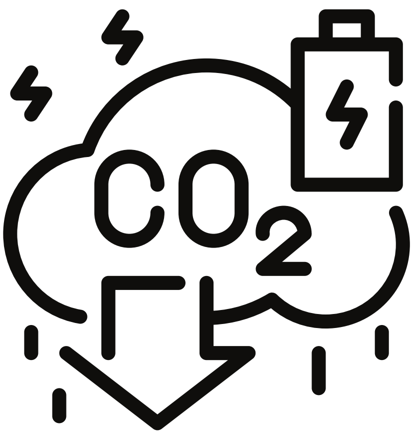
When we could, in a way, determine function from information, is it possible to engineer an entire biological system almost from scratch? Synthetic biology is about designing, building and testing such systems by arranging individual parts whose function is known, from a vast library, like lego blocks. It is similar to arranging the several components of an electric circuit, like a battery, a resistor, a switch, and a fuse. This has numerous applications.



Synthetic biology can be used to increase yield, and nutritional content, fight pests and tolerate climate change by using biofertilisers, microbial systems that produce essential nutrients, or engineering plants. Engineered biological systems could be used in pollution detection and control, using biosensors or metabolism that convert pollutants into harmless substances.

The same principles could be used to produce biofuels or bio solar cells to harness energy. They can also be used in various novel medicines, gene and cancer therapy, targeted drug delivery or a targeted attack on tumour cells; various kinds of vaccines and diagnostic tools have also been developed using such principles.





Finally, Synthetic biology has also made its way into industries, as people constantly look at more sustainable ways to produce chemicals, with low carbon emissions and low toxic effluents released. Biological systems producing novel materials are also being developed.

Applications of Synthetic Biology

Synthetic Biology has multifaceted applications in various domains, as listed above. The emphasis of synthetic biology in healthcare has been compounded in recent times. Synthetic biology enables designing, synthesis, testing and deploying antigens and variants with rapid results, high expression and capacity. It also allows for developing immunogens engineered for efficacy and high titer and produces rapid assays to purify the immunogens.

INDUSTRY

- Enzyme production
- Biofuels
- Bio-based specialty products
- Bulk chemicals

HEALTHCARE

- Drug design
- Immunotherapy
- Sustainably-produced medicines
- Vaccines

AGRICULTURE

- Sustainable farming
- Soil additives
- Bio-based specialty foods
- Disease-resistant plants

ENVIRONMENT

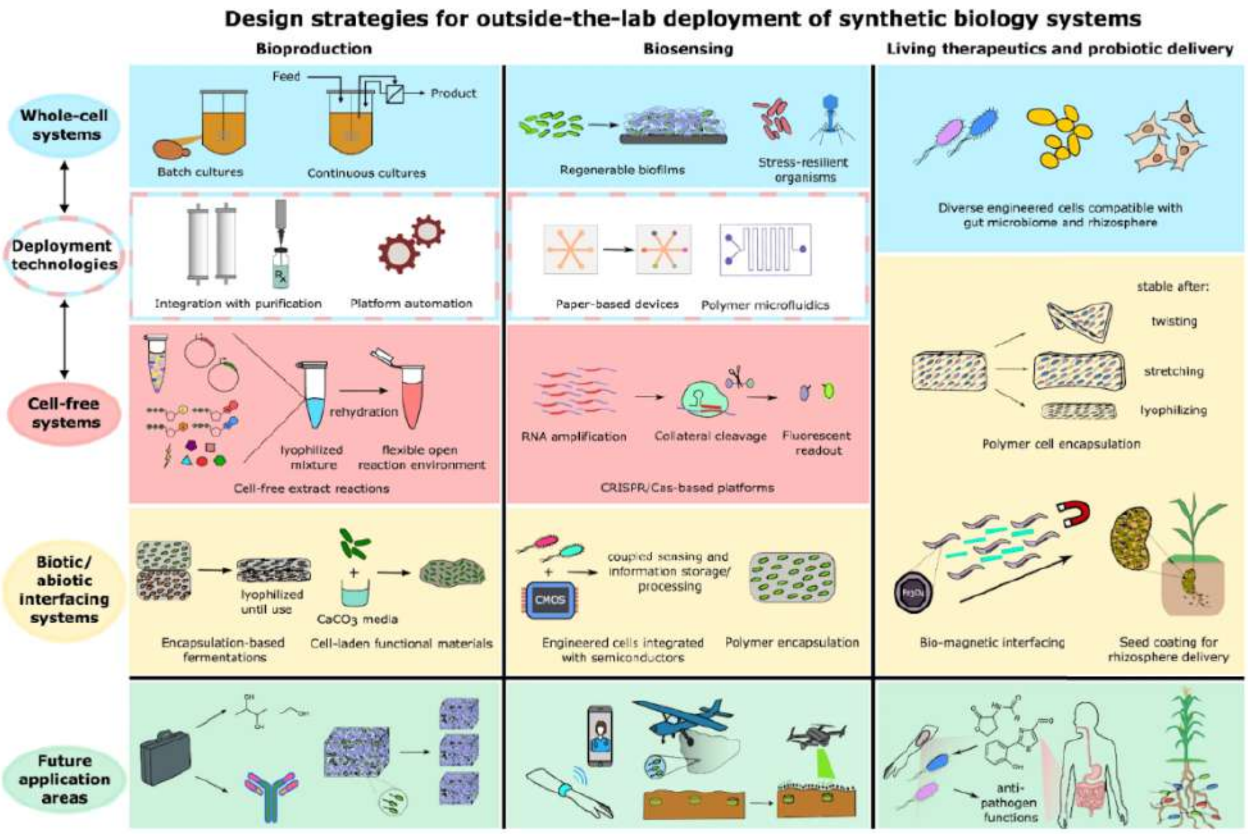
- Biofuels
- Biosensors for pollution
- Bioremediation
- Waste treatment

In the environmental and agricultural domains, significant biotechnology advances are opening up opportunities in producing biofuels and renewable chemicals as well as materials made from different types of renewable biomass. Recent breakthroughs include enzymes that break down the lignocellulose from agricultural residues to simple sugars.

In industrial applications, the development of synthetic enzymes that work in broader temperature ranges, with greater efficiency and other desired modifications can be enabled.

Inaccessibility to Synthetic Biology

While there are numerous prospects for synthetic biology, as illustrated in its applications, the most considerable concern is its inaccessibility. The resources that are required to begin experimenting are often expensive. To alleviate this problem, some recommendations are shown below-



Importance of Training High School Students in Synthetic Biology

As discussed above, synthetic biology has multiple applications; therefore, a lot of how we can explore more about synthetic biology can start when we are younger, so our understanding of the same grows deeper. However, school students are sparingly given any insights into synthetic biology.

This is important because it helps students envision biological processes, and even ponder what solutions can be created to problems that they frequently learn about, like environmental degradation and water scarcity, among others.

One way to do this is by giving high schoolers access to synthetic biology kits containing basic materials like pipettes, Eppendorf tubes, plasmids etc. Some basic experiments like bacterial transformation and plasmid isolation can also be performed.

There are multiple institutional collaborations underway to ensure that inexpensive, easy-to-use kits are made accessible such that hands-on demonstrations and exploratory biological experiments can be conducted in the classroom.

For, eg, students can use the kits to build genetic circuits, which they insert into microorganisms to manipulate the colour, smell, and shape of the organisms.

About iGEM

The iGEM Foundation is an independent, non-profit organisation dedicated to the advancement of synthetic biology, education and competition, and the development of an open, collaborative, and cooperative community.

The iGEM Competition season runs from May to October, and culminates in the Giant Jamboree in November. Teams spend the season learning about synthetic biology, developing their project ideas, gaining laboratory experience, and collecting and processing primary data from their experiments.

The Jamboree in November allows teams to present their projects to a panel of judges and their peers, and other iGEM teams.

High School iGEM program is an exciting way for students and instructors to learn about and engage in synthetic biology. High school teams participate in iGEM as part of the main competition. High school teams follow the same timeline, deadlines and attendance dates as collegiate teams. They also are responsible for all of the same Competition Deliverables (items needed to fulfil competition criteria), and are evaluated by judges using the same criteria as the collegiate teams. This is an exciting opportunity for high school members: not only will they be able to compete against other high schools, but they will have the great experience of the Giant Jamboree.