NSCEB
National Security Commission on Emerging Biotechnology

DNA 101: Reading, Writing, and Editing

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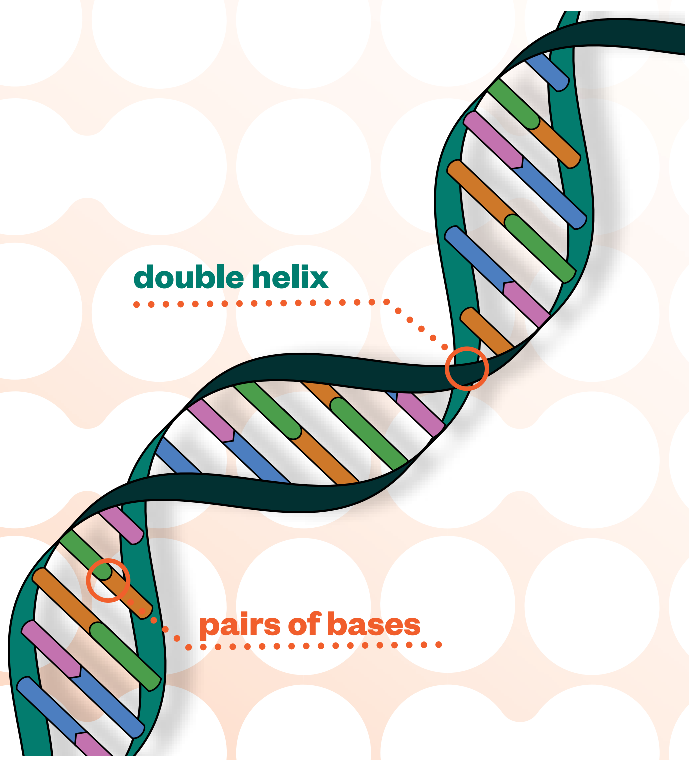
Introduction to DNA

DNA, the building block of life, is at the center of groundbreaking advancements, from gene therapies for sickle cell anemia to breakthroughs in agriculture and biomanufacturing. Understanding DNA empowers us all to participate in the responsible governance and ethical use of these life-changing technologies. DNA, short for deoxyribonucleic acid, helps all living things grow, survive, and reproduce. DNA is made up of four bases – adenine (A), cytosine (C), guanine (G), and thymine (T) – and these letters represent the DNA "code." Unique combinations of these bases make up genes, many of which provide instructions for making proteins. Proteins are large molecules responsible for many important functions in our bodies. The sum total of an organism's DNA is called its genome.

The common structure of DNA is often referred to as a "**double helix**". The steps of this twisted ladder are made of **pairs of bases**: (**A**) always pairs with (**T**), and (**C**) always pairs with (**G**). If you know the bases on one side, you can easily figure out the bases on the other side. The process of creating a copy of the original DNA is known as "replication." Advances in reading, writing, and editing DNA allow for the precise manipulation of genetic material, opening new possibilities across many fields.

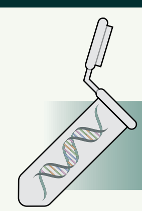


Reading DNA

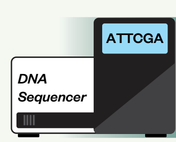
DNA sequencing involves reading the DNA code to find useful information, such as the presence of disease-causing genes. The advancement in DNA sequencing technology has enabled the reading of longer DNA fragments more quickly and efficiently. As a result, the cost of sequencing entire genomes has fallen significantly to just a few hundred dollars.[1] Newer sequencers work by simultaneously analyzing various parts of the genome or by pulling strands of DNA through small membrane pores using an electrical current. As a result, we can collect huge amounts of DNA sequence data.[2]

These data help us learn more about previously unknown links between genes and their functions, opening exciting possibilities around alternative food production, enhanced supply chain resiliency, innovative biofuels, and the prevention of future pandemics. It is important to consider which sequences are included in databases like the International Nucleotide Sequence Database Collaboration (INSDC)[3], and who is allowed to work with them.

Reading DNA steps



Researcher acquires DNA sample with unknown genetic sequence.



Researcher deposits DNA into the sequencer, where the sequencer amplifies and analyzes the DNA.

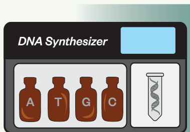
The sequencer generates the genetic sequnce of the DNA sample.

Writing DNA

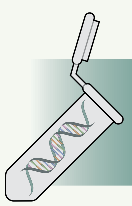
DNA synthesis is the process of writing DNA and has become an important tool in biotechnology. As a result, the demand for custom DNA has grown significantly.[4] Traditionally, DNA synthesis involved connecting short fragments of DNA, called oligonucleotides. New technologies have since developed that have automated the process and allow for writing longer, more complex strands of DNA. Enzymatic DNA synthesis, an emerging method, uses naturally occurring biological catalysts to synthesize DNA more accurately and efficiently.[5] Companies now offer custom synthesis services and benchtop DNA printers. Cheaper DNA synthesis allows researchers to conduct faster, more efficient gene design and testing, leading to the creation of larger gene datasets. This allows researchers to explore more genetic designs.[6] The integration of AI tools, already being deployed to generate new insights from large datasets, further amplifies the potential scope and impact of this technology.[7]

Writing DNA steps

Researcher creates genetic sequence of interest.



Researcher uploads the genetic sequence to a DNA synthesizer that assembles the genetic bases into the sequence of interest.



DNA synthesizer produces DNA strands with the genetic sequence of interest.

Editing DNA

Organisms' DNA has naturally evolved through mutation for billions of years. Through selective breeding, humans have shaped the DNA of animals and plants for ten thousand years. Recombinant DNA technology and gene editing have helped to speed and expand that process. Recombinant DNA technologies can be used to combine DNA from different sources enabling the creation of new genes with new functions. Gene editing tools like CRISPR* enable directed changes within an organism's own DNA sequence, from changing a single base pair to inserting sequences at a precise location.[8] CRISPR employs a type of molecule known as guide RNA and a protein called Cas to accurately identify and cut DNA sequences, potentially altering how a cell or organism functions. Used responsibly, CRISPR, along with other advances in DNA editing, is allowing scientists to develop better diagnostic tools, more resilient plants and animals, and advanced industrial products. As we navigate this era of genetic discovery, the advancements in reading, writing, and editing DNA are rapidly transforming science and technology, presenting unprecedented opportunities for innovation and progress.

Editing DNA steps

Researcher acquires DNA sample that needs to be modified.

Researcher uses a gene editing tool like CRISPR-Cas9 to edit a section of the DNA.

The cell's natural repair mechanism repairs the DNA with the new genetic sequence.

*CRISPR stands for clustered regularly interspaced short palindromic repeats

Sources

1 NIH National Human Genome Research Institute. "DNA Sequencing Costs: Data"
2 Congressional Research Service. "Digital Biology: Implications of Genetic Sequencing"
3 International Nucleotide Sequence Database Collaboration. https://www.insdc.org/
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5 Damiano Verardo et al. "Multiplex enzymatic synthesis of DNA with single-base resolution"
6 Hughes R., Ellington A. "Synthetic DNA Synthesis and Assembly: Putting the Synthetic in Synthetic Biology"
7 Miller, J. "Labor, OPM, Census dialing up AI tools to crunch data, improve mission outcomes"
8 NIH National Human Genome Research Institute "Recombinant DNA Technology"

For any questions about this white paper, or related work at the National Security Commission on Emerging Biotechnology, please contact us at ideas@biotech.senate.gov.

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