Teacher's Guide

Investigating the History of Biotechnology

Grade Level: Middle and high school

Subject area(s): Biology; Life Science; Genetics

Time required: 50 minute

Learning Objectives:

Summary: This activity examines the history of biotechnology from 1920 to present day and its impact on human health. Students rotate through a series of ten stations to read about biotechnology achievements over the decades and answer questions at each station. The activity can be done similar to a web quest where students can use their computers to answer questions and learn more about each achievement. The activity's format allows flexibility in classroom use.

Lesson Background: Deoxyribonucleic acid (DNA) is the biological molecule that gives each organism its unique genetic blue print. Its structure, shown in Figure 1, is a double stranded helix that measures 3 nanometers between the strands[1]. DNA is composed of four nucleotide bases, adenine, guanine, cytosine, and thymine that are arranged in specific sequences called genes. DNA, located in the nucleus of the cell, controls all of the cell's activities. No two people, except identical twins, have the exact same DNA sequence.

Along with being the genetic code, DNA has been manipulated throughout history for food and pharmaceutical production. The earliest application of DNA biotechnology was by the Egyptians who discovered that yeast could be used to make bread rise[2]. This gave way to softer, better tasting bread and is still being used today. Yeast fermentation technology has been expanded to make yogurt, beer, and wine. Along with food production, DNA biotechnology has been expanded to the synthesis of bovine growth hormone to increase cows milk production and human growth hormone for treatment of children with human growth hormone deficiency[2]. Organisms have also been genetically modified by inserting foreign DNA into their genome to make them grow faster, larger, more nutritious, and disease-resistant.

While DNA biotechnology has increased and enhanced human lives, there are many ethical concerns with using it. One concern is the adverse health effects that might be caused by consuming genetically modified organisms. Also, the pollen from GMO plants may travel and contaminate non-GMO plants on farm that do not want to plant genetically modified crops. Some fear of the rise of "super" organisms due to the inserted foreign DNA that could disrupt or destroy ecosystems. DNA technology is an example of how nanotechnology can have a significant impact on everyday life. With the advent of CRISPR technology we now have a powerful tool for editing genomes. CRISPR allows researchers to alter DNA sequences and modify gene function. The field is being touted to have many potential applications including correcting genetic defects, treating and preventing the spread of diseases and improving crops.

This activity will examine the history of DNA and other biotechnology breakthroughs from the 1920s to present day.

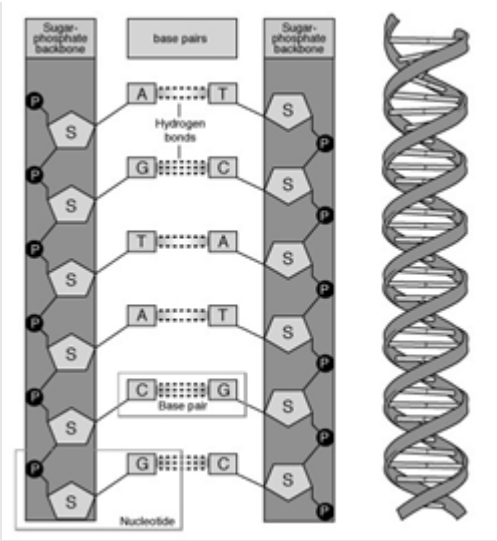

Figure 1: A DNA strand is shown on the right. The double helix is formed by the pairing of the nucleotide bases which is shown on the left. Adenine pairs with thyamine and guanine with cytosine[3].

References:

1. National Nanotechnology Coordinated Infrastructure poster. "Nanotechnology: Learn about the Very Small": https://www.nnci.net/sites/default/files/inline-files/NNCI%20Edu%20Poster%20Update%205-1-18CME.pdf
2. Access Excellence @ the National Health Museum Resource Source. 2010. 5 July 2011 http://www.www.accessexcellence.org/RC/AB/BA/DODpub/dodles1a.php
3. Access Excellence @ the National Health Museum Resource Source. 2010. 5 July 2011 http://www.accessexcellence.org/RC/VL/GG/dna2.php

Pre-requisite Knowledge: Understanding of cells, DNA, and genes.

Materials:

- Biotechnology history cards and props

Safety Information: No safety issues

Advance Preparation:

Set up stations that highlight the history of biotechnology. Each station will have a picture, a commentary, and a list of three or more questions. The station will also include props for students to examine. Make sure students have access to computers to find information of questions they cannot answer or want to explore further.

Suggested Teaching Strategies: The stations can serve as a jumping off point for students to explore topics more deeply. The teacher could assign students parts of the timeline to develop a PowerPoint to share with the class to extend student understanding and knowledge about the topics.

Directions for the Activity:
Set up the ten stations that will represent a timeline of biotechnology. Students will rotate at each station for 5 minutes to read the commentary and answer the questions. Each station should have these items: a picture with the station historical time, a commentary explaining the time era, questions, and props that pertain to that era. An alternative method is to use the PowerPoint History of Biotechnology and answers the questions as a class group discussion. In both methods, students should be given time to use their computers to answer questions they do not know the answers for. The lesson can be treated as an interactive webquest where the students follow the time line and use their computers to answer the questions and learn more about each part of the timeline.

Station 1: 1920s (Penicillin)
Commentary: In the 1920s Alexander Fleming accidently discovered penicillin, a powerful antibiotic that is used to treat bacterial infections. Penicillin is derived from fungi. Prior to the 1920s, even minor bacterial infections were deadly. While penicillin was instrumental in treating diseases, such as strep throat, by end of the 1940s bacteria resistance to the drug began to occur.

Questions:
1. What is an antibiotic? Compounds that kill bacteria.
2. Which organism can antibiotics be used to kill? Bacteria
3. How does an antibiotic differ from a vaccine? Antibiotics kill bacteria to treat an infection. Antibiotics are not effective against viruses. Vaccine are used to prevent viral and bacterial infections.
4. What happens if a person fails to take antibiotics correctly? Bacteria can become resistant, which makes the antibiotic ineffective.

Props: Microscope pictures of different strains of bacteria.

Station 2: 1950s (Eradicating Polio)
Commentary: Poliomyelitis is an infectious crippling disease that is caused by a virus. In the early 1900s, many people, especially children, were left paralyzed as a result of being infected. Some even ended up spending their life in an iron lung. In the 1950s Dr. Jonas Salk developed the polio vaccine, which has nearly eradicated polio in the US.

Questions:
1. What is a vaccine? A substance that is used to prevent diseases.
2. What role do vaccines play in preventing and treating diseases? They are used to make a person immune to a disease by administering dead or weakened pathogens.
3. Name three diseases that have vaccines. Measles, mumps, rubella, polio, flu, small pox.
4. How have vaccines improved human health? They have led to the eradication of many once deadly diseases.

Props: Microscope pictures of polio virus, pictures of people with polio.

Station 3: 1950s (Discovering DNA's function)

Commentary: Prior to the 1950s, little was known about structure and function DNA. Many experts hypothesized that proteins were the genetic material for organisms. In 1952, Alfred Hershey and Martha Chase conducted their famous experiment to confirm that DNA was the genetic material.

Questions:

1. What is the central dogma in biology? DNA →RNA →Proteins
2. Why were proteins first considered to the first genetic material? Little was understood about the function of DNA, but much was known about proteins.
3. How did scientist determine DNA was the first genetic material? They used bacteria and radioactive probes to determine if DNA or proteins were the genetic material.

Props: Pictures of Drs. Hershey and Chase and detailed explanation of their experiment.

Station 4: 1960s (Discovering DNA's Structure)

Commentary: While Hershey-Chase determined the function of DNA, Crick, Watson, and Rosalind Franklin determined the structure of DNA. DNA is double helix composed of nucleotide bases, a phosphate group, and a sugar. Crick and Watson won the Nobel Prize in 1963.

Questions:

1. What does DNA stand for? Deoxyribonucleic acid.
2. What are the nucleotide bases and how are they paired? Adenine (A), cytosine (C), guanine (G), and thymine (T). Pairing rule: A to T and G to T.
3. If DNA has 20% As, how many Cs does it have? 30%
4. If there so few bases, why are people so different? The order of the bases impacts the genetic variability.

Props: DNA models and pictures of Drs. Crick, Watson, and Franklin

Station 5: 1970s (Recombinant technology)

Commentary: Pharmaceuticals: Prior to the 1900s, diabetes was a certain death sentence. Doctors often used crude methods for treatment since little was known about the role of insulin in regulating blood glucose. Insulin was first discovered in the 1920s as an effective treatment for diabetes. Early formulations were extracted from animal sources and were impure, which often caused adverse reactions. In the 1970s, E coli were used to make synthetic insulin, which resulted in larger quantities that could be purified and safely injected.

Questions:

1. What are some examples of biological pharmaceuticals? The pharmaceutical include insulin, vaccines, and antibodies.
2. Which organisms are used to make medications? Usually *E. coli* and bacteriophages (viruses used to deliver foreign DNA to the *E. coli*)

3. What is the name of the process used to make biological pharmaceuticals? Recombinant DNA technology.
4. How can you tell if a biological was made using E coli or another organism? Any medication that has rDNA on the label is a biological pharmaceutical.

Props: Handouts or boxes for Humira, Humalog, human growth hormone (somatrophin)

Station 6: 1980s (PCR)

Commentary: Polymerase Chain Reaction (PCR) is a process in which DNA is rapidly replicated using primers, enzymes, and temperature cycles. It was invented by Kary Mullis in 1983. PCR is used to amplify gene sequences and rapidly replicate small samples. Before PCR, small DNA samples were difficult, if not impossible to analyze. It is used for forensic and genetic analysis.

Questions:

1. How does PCR compare to DNA replication? PCR while it replicates DNA, uses artificial means. PCR can also be used to replicated certain areas of DNA. Cells undergo DNA replication in preparation for mitosis and it is carefully controlled.
2. What mathematical function describes the amount of DNA produced during PCR? 2^x
3. After 30 rounds of PCR, how much DNA would be produced? 2^{30}=1 billion copies

Props: Pictures of DNA replication

Station 7: 1996-2005 (GMOs-plants)

Commentary: Genetically Modified Organism (GMOs): GMOs, which were first introduced in 1996, are organisms that have foreign DNA inserted into their genome. Expression of the foreign DNA allows the organism to be more nutritious and disease resistant. GMOs have also increased the size and yield of organisms. Many commonly consumed GMOs are corn, papaya, and soybeans.

Questions:

1. Why would some farmers not want to plant genetically modified crops? The plants are not "natural" and may disrupt the environment and other organisms in the ecosystem. Some of pests are starting to develop mutations that allow them to attack disease-resistant GMOs.
2. How would a neighboring farmer who is planting genetically modified plants impact a farmer who is not? The seeds can travel in the wind and pollinate plants that are not genetically modified, which can result in genetically modified offspring. If the farmer is an organic farmer, genetically modified plants are not desired.
3. What are the ethical concerns of creating and eating GMOs? The first concern is, should GMOs be created? Other ethical concerns include: the effect of foreign DNA on the organism, the environmental impact, and the effect on other species (includes the species that will be ingesting them).

Props: Soy beans and other GMOs (papaya, corn)

Station 8: (GMOs-animals)

Commentary: GMO animals: Currently, the only types of GMOs that are approved for human consumption are plants. However, animals are being genetically modified for desired properties such as less feathers, increased nutrition, faster growth, and disease resistance.

Questions:

1. How can a chicken be born without feathers? The chicken can be genetically altered to silence or knock out the gene that produces feathers. Chickens without feathers can be used to breed other chickens without feathers.
2. Why would you want to raise featherless chickens? To make chicken slaughter easier, no feather plucking needed.
3. Are there any issues associated with this organism? Without feathers, the chickens are more susceptible to disease, sunburns, and predators (inability to fly). Their ability to regulate body temperature may also be impacted.

Props: Pictures of genetically modified animals

Station 9: Enter CRISPR

Commentary- Clustered regularly interspaced short palindromic repeats, CRISPR, were discovered independently in three parts of the world beginning in 1987 with the acronym being proposed in 2001. CRISPR allows the alteration of DNA sequences and modification of gene function. The process has many potential applications including correcting genetic defects, treating and preventing the spread of diseases and improving crops.

Questions:

1. How was CRISPR discovered? Researchers noticed nucleic acid sequences in archaea and bacteria contained copies of virus genes. It appeared that somehow these organisms had "stolen" genes out of viruses. Research began to determine how and why this happened.

2. What did the researchers discover about the "stolen" genes? They protected the cells against infection. Researchers were able to determine that if a virus tried to infect the bacteria or archaea, CRISPR-associated (cas) enzymes would find and break the infectious nucleic acid sequences identified by the code. This would destroy any potentially deadly viruses.

3. Why is CRISPR so important? The technology has great scientific interest because it is faster, cheaper, more accurate, and more efficient than other existing genome editing methods. The method of editing gene sequences is of great interest in preventind and treating of human diseases.

Station 10: Present Day (Who Owns the Genome)

Commentary- In 2013, the US Supreme Court ruled that naturally occurring DNA cannot be patented. Several companies have created and manipulated DNA sequences for agriculture and pharmaceutical purposes. The court ruled that manipulated DNA can be patented.

Questions:

1. What defines natural DNA? DNA produced without human intervention.
2. Do companies have the right to patent DNA? Open ended question, great point for discussion.
3. How do patents impact scientific progress? They can help in moving science forward, but also can prevent access for those who cannot afford patented items.
4. What are the concerns with creating synthetic DNA? The way in which it is used can be a concern. Refer to the section on recombinant technology and GMOs.

Props: News articles

Assessment: Review all the questions with the students at the end of the class or the next class. If there is more time, assign students one of the stations to perform additional research on a topic that pertains to the station.

Additional Resources:

- Learn Genetics Virtual Lab: https://learn.genetics.utah.edu/content/labs/
- Learn Genetics Basic Genetics: https://learn.genetics.utah.edu/content/basics/
- What is Polio – CDC: https://www.cdc.gov/polio/what-is-polio/index.htm
- Alexander Fleming Discoverer of Penicillin: National Center for Biotechnology Information https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4520913/
- Vaccines the Basic – CDC: https://www.cdc.gov/vaccines/vpd/vpd-vac-basics.html
- Hershey Chase Experiment: https://en.wikipedia.org/wiki/Hershey%E2%80%93Chase_experiment
- Hershey and Chase: DNA is the genetic material – Kahn Academy: https://www.khanacademy.org/science/biology/dna-as-the-genetic-material/dna-discovery-and-structure/v/hershey-and-chase-conclusively-show-dna-genetic-material
- Discovery of DNA Structure and Function: Watson and Crick - Pray, L. (2008) Discovery of DNA structure and function: Watson and Crick. Nature Education 1(1):100. Accessed at: https://www.nature.com/scitable/topicpage/discovery-of-dna-structure-and-function-watson-397/
- History of DNA – LUNADNA: https://www.lunadna.com/blog/history-of-dna/
- The Nobel Prize in Physiology or Medicine 1962: https://www.nobelprize.org/prizes/medicine/1962/summary/
- History of Insulin: https://www.diabetes.org/blog/history-wonderful-thing-we-call-insulin and https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3714061/
- Role of Recombinant DNA Technology to Improve Life by S. Khan et al - National Center for Biotechnology Information. Accessed at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5178364/

- History of PCR: https://www.thermofisher.com/us/en/home/brands/thermo-scientific/molecular-biology/molecular-biology-learning-center/molecular-biology-resource-library/spotlight-articles/history-pcr.html; https://en.wikipedia.org/wiki/History_of_polymerase_chain_reaction; and https://knowledge.pcrdrive.com/wiki/Importance_and_History_of_PCR
- Science and History of GMOs and other Food Modifications – FDA: https://www.fda.gov/food/agricultural-biotechnology/science-and-history-gmos-and-other-food-modification-processes
- From Corgis to Corn: A Brief Look at the Long History of GMO Technology – Science in the New, Harvard University: http://sitn.hms.harvard.edu/flash/2015/from-corgis-to-corn-a-brief-look-at-the-long-history-of-gmo-technology/
- What is CRISPR – New Scientist: https://www.newscientist.com/term/what-is-crispr/
- CRISPR Gene Editing: https://en.wikipedia.org/wiki/CRISPR_gene_editing
- Can Genes be Patented? – NIH: https://ghr.nlm.nih.gov/primer/testing/genepatents
- What are the Ethical Concerns of Genome Editing? – NIH: https://www.genome.gov/about-genomics/policy-issues/Genome-Editing/ethical-concerns

Next Generation Science Standards:
MS-LS4-4: Gather and synthesize information about technologies that have changed the way humans influence the inheritance of desired traits in organisms.
MS-LS1-3: Science is a human endeavor.
MS-LS3-1: Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may real in harmful, beneficial or neutral effects to thee structure and function of the organism.
MS-LS3.A: Inheritance of traits
MS-LS3.B: Variation of traits
HS-LS3-3: Science as a human endeavor
HS-LS3-1: Ask questions to clarify relationships about the role DNA and chromosones in coding the instructions for characteristic traits passed from parents to offspring.
HS-LS1.A Structure and function
HS-LS1.B Growth and development of organisms
HS-ETS1-1 and **1-3:** Influence of science, engineering and technology on society and the natural world

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