# PLTW Science Frameworks

**PLTW Course:** Biotechnical Engineering (BE)

**Science Strand being addressed: Life Science - Strand 4**
**Science Sub-strand being addressed:** Evolution in Living Systems – Sub-strand 3

**Science Standard being addressed:** 9.4.3.1

## Overview:

**Science Standard and Benchmarks:** 9.4.3.1, 9.4.3.1.1, 9.4.3.1.3

**Standard 9.4.3.1:** Genetic information found in the cell provides information for assembling proteins, which dictate the expression of traits in an individual.

**Benchmark 9.4.3.1.1:** Explain the relationships among DNA, genes and chromosomes.

**Benchmark 9.4.3.1.3:** Describe the process of DNA replication and the role of DNA and RNA in assembling protein molecules.

**Correlation to AAAS Atlas (Benchmarks for Science Literacy):**
5B/H3*, 5B/H4*, 5C/H4a, 5C/H4b, 5C/H4c, 5C/H9**, 12CLS1, 12CLs1.3, 12CLS2, 12CLS2.1

- The information passed from parents to offspring is coded in DNA molecules long chains linking just four kinds of smaller molecules, whose precise sequence encodes genetic information. 5B/H3*
- Genes are segments of DNA molecules. Inserting, deleting, or substituting segments of DNA molecules can alter genes. An altered gene may be passed on to every cell that develops from it. The resulting features may help, harm, or have little or no effect on the offspring's success in its environment. 5B/H4*
- The genetic information encoded in DNA molecules provides instructions for assembling protein molecules. 5C/H4a
- The genetic information encoded in DNA molecules is virtually the same for all life forms. 5C/H4b
- Before a cell divides, the instructions are duplicated so that each of the two new cells gets all the necessary information for carrying on. 5C/H4c
- Some protein molecules assist in replicating genetic information, repairing cell structures, helping other molecules get in or out of the cell, and generally catalyzing and regulating molecular interactions. 5C/H9** (SFAA)

- The cell (12CLS1)
    - Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires. (12CLS1.3)
- Molecular basis of heredity (12CLS2)
    - In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes (as a string of molecular "letters") and replicated (by a templating mechanism). Each DNA molecule in a cell forms a single chromosome. (12CLS2.1)

## **Essential Understandings/Big Ideas**:

- Proteins, special molecules made of amino acids that are bonded together in a very specific order, control the majority of chemical reactions in living systems.
- It is the order of these amino acids that determine the shape and chemical properties of the proteins. DNA carries the information for how to assemble proteins found in any organism.
- Each cell contains a complete set of all DNA, and these DNA molecules are passed from parent to offspring. This is the molecular basis of genetics.
- A segment of DNA that codes for one protein (or in some cases - one RNA molecule) is called a gene.
- DNA strands are tightly coiled to form a structure called a chromosome, and there are thousands of genes on each chromosome.
- During cell division, DNA is copied in a process called replication, which uses the current strand of DNA as a pattern for assembling the new strand.
- DNA also contains the directions for making a protein.
- In order to make a protein, the gene of DNA must be copied to RNA in a process called transcription.
- Following transcription, the RNA forms a complex with a ribosome.
- With the help of the ribosomes and several other molecules, the RNA serves as the pattern to join amino acids to constitute a protein during the process called translation.

Genetic engineering and recombinant DNA technology are fundamental aspects of modern biotechnology. A variety of methods and applications of genetic modification are used in fields ranging from medicine and agriculture to environmental remediation. In agriculture, genes coding for characteristics such as drought, frost, pest, or spoilage resistance can be genetically transferred into plants. In bioremediation, bacteria can be genetically modified with DNA enabling them to breakdown oil spills. In medicine, genetic diseases are beginning to be treated by gene therapy by genetically altering a faulty genome with good copies of the defective gene that causes their illness.

**What should students know and be able to do [at a mastery level] related to these benchmarks?**

Students should be able to:

- Explain the relationships among DNA, genes and chromosomes.
- Describe the structure of DNA.
- Describe the process of DNA replication.
- Describe the role of DNA and RNA in assembling protein molecules (transcription and translation).
- Understand that DNA is the genetic code passed on from parent to offspring.
- Explain how altering the DNA of an organism will affect the proteins made by that organism.
- Identify several ways DNA or the protein products are utilized in biotechnical applications (i.e., DNA analysis of pathogens, bioinformatics, forensics, genetically modified organisms, etc.)

# Misconceptions:

## Student Misconceptions

- DNA only consists of genes (protein coding segments). Students do not realize the amount of non-protein coding segments in DNA and the importance of these segments in structural and regulatory roles.
- Chromosomes are made of several strands of DNA twisted together. Students find it difficult to accept that a chromosome consist of only one continuous strand of DNA.
- All of the chromosomes of an organism are the same (carry the same genes). Although true of homologues, this is clearly not true of non-homologous chromosomes.
- A gene is a trait. Students do not understand that genes code for specific proteins and that the production and/or function of these proteins results in the traits.
- Genes for specific traits are only found in the cells that are affected (i.e., hair color genes are only found in hair follicle cells). It is important for students to understand that the entire genome is found in every cell of every tissue of the body, but that the expression of a specific gene is controlled by regulatory mechanisms (operons in prokaryotes and several levels/types of control in eukaryotes).
- DNA replication, RNA transcription, and translation (protein synthesis) occur continuously - all of the time, in every cell. Students do not connect that replication is part of the cell cycle for cell division, nor do they fully comprehend the regulation involved in transcription and translation.
- Manipulating DNA and cloning of cells is not yet possible. Students should know that these technologies are well developed and are widely used to produce many common products, such as pharmaceutical drugs, genetically modified plants, and transgenic animals.
- Genetic technology is simple. Students do not have a complete understanding of the complexity of genetic technology nor appreciate the limitations of the technology.

# Teacher Resources:

## Teacher Notes

Since our understanding of DNA and methods of manipulating DNA have advanced so much in the past 20 years, it is now possible to apply DNA technology to real-world problems such as in the areas of medicine and agriculture. There are several activities in the Biotechnical Engineering curriculum that help students learn about the structure and function of DNA, then apply this knowledge to solve problems.

- **Project 3.1.1 DNA Modeling**
  Students research the structure of DNA and build a scaled up model display in the classroom using materials of their choice. The project also requires students to create a visual product describing the scientists involved in the discovery of DNA's structure and the basics of replication, transcription, translation, and genetic engineering.

  *Common pitfalls:*
  - Many teachers and students have struggled with the angstroms as a unit for the construction of the students' DNA models. An angstrom (Å) is equivalent to one tenth of a nanometer (nm), or $10^{-10}$ meters. Some resources for the structure of DNA will use angstroms, where others will use nanometers. It is helpful to make sure students understand that 1 nm = 10 Å.
  - The correct measurements for DNA are as follows: If the model is oriented with the z-axis in the vertical position, one full turn of the double helix is 34 angstroms in height. There are 10 base pairs (stacked up on top of each other) per turn, so the distance between adjacent bases would be 3.4 Å. This number is used in the rubric for scoring students' models in Project 3.1.1.
  - **Note:** The teacher may direct students to the Bio-Coach activities of the Biology Place website remediation in the fundamental understanding of gene expression is required:
    http://www.phschool.com/science/biology_place/biocoach/index.html

- **Activity 3.1.2 Rapid Pathogen Identification**
  Students assume the role of pathologists and work in teams to identify a mock pathogen that is afflicting a population in Washington D.C. The students are supplied with pathology reports and DNA sequence data, which was received in increments over a series of days. These reports include symptoms and fragmentary sequence data. The students query genome databases with short (500-900 base pair) DNA sequences. From this information, they make decisions as to which pathogens or pathogen families are present. Based on the correlation of symptoms and database matches, they rank and hypothesize which pathogens are responsible for the outbreak in order to better fight the disease. The students are given new data every day to help bring them closer to an answer.

*Common pitfalls:*

- The teacher needs to preview the **www.ncbi.nlm.nih.gov** website prior to the activity as links and button locations can change periodically. The following instructions are a general guide that will help when navigating the BLAST Website.

**BLAST – Genetic Sequence Identification Process:**

1. Access **www.ncbi.nlm.nih.gov**
2. Click the *BLAST* tab on the home page.
3. Locate the *Nucleotide* category.
4. Click *Nucleotide-nucleotide BLAST (blstn)*.
5. Copy the desired genetic sequence.
6. Paste the genetic sequence into the *Search* window.
7. Click the *BLAST!* button.
8. Click the *FORMAT!* button.
9. Scroll down to the area labeled *Sequences producing significant alignments* and locate the first sequence. This is the most likely candidate for the genetic sequence that was pasted into the BLAST search.

- **Project 3.1.5 CSI Forensic Techniques**
  Students learn about various analysis methods used in forensic science to solve a crime. They apply those techniques to solve a theoretical crime. The part of this project most relevant to this standard is when the students are gather and analyze DNA sequences taken from the crime scene using the BLAST search program.

  *Common pitfalls:*

  - Teachers may need to find supplementary activities to help students to learn the forensic techniques necessary to solve the crime scene. Many companies offer ready-to-go crimes scenes and forensics lab kits. It is best to focus on forensic techniques that utilize biology and biotechnology, such as fingerprinting, DNA analysis (including DNA "fingerprinting", or gel electrophoresis), blood splatter analysis, blood typing, and hair and fiber microscope analysis.

Some possible resources for such materials are listed below:

Wards Natural Science http://wardsci.com/category.asp_Q_c_E_1610_A_Forensic+Activities.
Carolina Biological Supply Company.
http://www.carolina.com/category/life+science/forensics.do?nType=1.
The Science Spot http://sciencespot.net/Pages/classforsci.html.
CSI - The Experience: Web Adventures http://forensics.rice.edu/html/onlineactivities.html.
Crime Scene store http://www.crimescene.com/store/.

- **Activity 3.1.6 Making *E.coli* glow like a Jellyfish**
  The students have a opportunity to carry our their own genetic engineering experiment by genetically transforming *E.coli* with a plasmid vector that carries genes for ampicillin resistance and the green fluorescent protein (GFP). The students will explore the process of transformation and analyze their experimental results as well as make the connection between genes and protein products.

  *Common pitfalls:*
  - Unless they have significant background knowledge, students really struggle to understand all of the complexities of genetically transforming bacteria and how operons control the transcription of a gene. They also fail to understand the differences between prokaryotic and eukaryotic genes and control (i.e., eukaryotic genes have introns, operons are only used as a control element in prokaryotic organisms, etc.). Depending on the level of your students, you may need to supplement with some lessons on DNA regulation, transformation, and operon mechanisms.

    There are several videos and other resources that can facilitate this process:
    - PBS *DNA* Episodes and companion website http://www.pbs.org/wnet/dna/index.html.
    - J. Craig Venter: Designing Life - 60 Minutes episode (November 21, 2010) http://www.cbsnews.com/video/watch/?id=7076435n&tag=contentMain;contentBody .
    - CSHL's DNA Learning Center - 3D Animations Library http://www.dnalc.org/resources/3d/index.html.
    - *Biology*, 7ed (Raven & Johnson) Chapter 16 animations http://highered.mcgraw-hill.com/sites/0072437316/student_view0/chapter16/animations.html.

  - Sterile technique should be emphasized during this activity as students sometimes are fearful of working with *E. coli* bacteria. Teachers can make it more relevant by discussing any recent food-contamination stories or antibiotic resistance due to the over-use of antibiotics.

- **Activity 3.1.7 Designer Genes: Industrial Application of Genetic Modification**
  Students design an industrial application of recombinant DNA technology using genes for fluorescent proteins. The students are asked to identify a problem and design a solution which will "improve the human condition" using the fluorescent proteins and gene modification. Students communicate conceptual models and explain how their design will solve the problem as well as meet legal concerns of federal regulatory agencies.

  *Common pitfalls:*
  - As in 3.1.6, students have a hard time understanding the complexities of inserting a eukaryotic gene into a prokaryotic organisms and how to control the gene

expression using an operon. Teachers may need to break up the activity into smaller “tasks” to provide regular feedback to students and help them to identify their misconceptions. For example, ask students to first brainstorm and propose a problem or question they hope to solve that meets the requirement of “improving the human condition”. Ask teams to submit their problem statement for review, and discuss it with students before they move on to the next phase of their design (identifying the organism(s), vector, gene(s), and operons they will use, etc.)

## New Vocabulary

- bioinformatics - The generation or creation, collection, storage (in databases), and efficient utilization of data or information from genomics, combinatorial chemistry, proteomics, and DNA sequencing research.
- deoxyribonucleic acid (DNA) - The chemical basis for genes; consists of nucleotides in a double helix.
- double helix - The normal structural configuration of DNA consisting of two helices winding about the same axis.
- eukaryote - An organism with cells that contain a nucleus and membrane-bound organelles.
- gene - A natural unit of the hereditary material, which is the physical basis for the transmission of the characteristics of living organisms from one generation to another
- nucleic acid - A large molecule composed of nucleotide subunits.
- nucleotide - The subunit that polymerizes into nucleic acids (DNA or RNA and consists of a nitrogenous base, a sugar, and a phosphate group.
- prokaryote - An organism lacking a true nucleus, such as a bacterium.
- protein - A large molecule composed of one or more chains of amino acids in a specific order, required for the structure, function, and regulation of the body's cells, tissues, and organs.
- replication - The process of making an identical copy of a section of double-stranded DNA, using existing DNA as a template for the synthesis of new DNA strands.
- recombinant DNA - Novel DNA sequence formed by the joining, usually in vitro, of two non-homologous DNA molecules.
- ribonucleic acid (RNA) - A single-stranded nucleic acid similar to DNA but which has ribose sugar rather than deoxyribose, and uracil rather than thymine as one of the pyrimidine bases.
- transformation - The process by which an organism (usually bacteria) takes up foreign DNA from its environment.
- transcription - The enzyme controlled process of making an RNA copy of the DNA gene sequence in the nucleus.
- translation - The process of using the sequence of codons in the mRNA to sequence and connect the amino acids as a specific protein is created.

# Vignettes:

## Vignette #1

*The students are trying to understand the process of GFP transformation of E.coli. This conversation illustrates how a teacher might lead a student to a deeper understanding of the process by making the student back up their explanation of their results with evidence.*

Teacher: Can you tell me how you can be sure that the transformed *E.coli* made the GFP and we didn't just add the GFP with the plasmid?

Student: Well... When you came around to give us the plasmid to transform the *E.coli,* you shined a UV light on it, and it wasn't green.

Teacher: Good, if the GFP were in with the plasmid, you would have seen it glow green. Can you think of any other proof that it was produced by the transformed *E.coli*?

Student: Let me think... I know! If the GFP was in with the plasmid, then the *E.coli* without the arabinose trigger would be green as well, but they are not.

Teacher: Exactly, by adding the arabinose operon sequence, we can control the expression of the GFP. Can you think of a way you can use that idea for your next assignment?

Student: Maybe we can make grass change color if it has had to much fertilizer.

Teacher: It sounds like you have some things to talk about with your group. Let me know if you need any help.

## Vignette #2

*In this vignette the class is using their knowledge and research to build a structurally accurate model of DNA. In this conversation the teacher stresses that the structure of DNA is important for how DNA performs its function of storing, protecting and accessing information for making new proteins.*

Student: I am confused... I can't get the my two strands of DNA in my model to line up with one another.

Teacher: What dimensions are you using?

Student: We chose to have one centimeter equal to one angstrom. But, the dimensions of the two separate strands all check out. It's just that the bases don't line up when we try to connect them in the middle with our hydrogen bonds.

Teacher: What do you know about the two strands?

Student: They are made of nucleotides. The phosphates and sugars make the backbone, and the bases stick out like rungs of a ladder. The bases meet in the middle and are connected by hydrogen bonds. The two strands are supposed to be 20 angstroms, so 20 centimeters, across in diameter.

Teacher: Keep going...

Student: The phosphate of one nucleotide connects to the 3rd carbon of the sugar of the previous nucleotide.... oh, wait! And, the strands are antiparallel! That's what we forgot! We need to flip one strand around so it runs the opposite direction of the other one!

Teacher: Great. You may have found your solution. Why is that important for the function of DNA?

Student: When DNA is transcribed into RNA, only one strand is used as the template for that gene - the strand that runs 3' to 5'.

Teacher: Exactly. Now, see if you can get those strands put together and twisted into a …

Student: … Double helix!

# Assessment:

## Assessment Methods

### 3.1.1 Assessment

- The students work in teams of two or three to create a museum display that will ultimately compete against other displays at a showcase. The displays will be judged by high school students for creativity and intrigue in addition to teachers and scientists that will judge for factual accuracy.
- The museum display must include:
    - 3D physical model of DNA (<50cm tall, other specifics below).
    - Sketches of the model with dimensions.
    - Optional: 3D model using Inventor software.
    - Scale bar and legend describing molecules within the DNA structure (nitrogen bases, deoxyribose sugar, phosphate, hydrogen bonds, backbone, etc.).
    - A representation of key discoveries (and corresponding scientists) leading to the final 3D structure of DNA, including the interpretation of x-ray crystallography.
    - An explanation of how the structure of DNA facilitates replication for cell division, gene expression, and protein synthesis; and allows manipulation via recombination.
    - Poster, website, or flip chart with questions. The display that accompanies your 3D model may be in any form you choose (poster, website, flip chart with questions, etc.) as long as it would be suitable for display at a museum.

- The students grade their own team's DNA exhibit, using Project 3.1.1 DNA Assessment form. Each team member must complete his/her own evaluation of the group. Students must evaluate at least three other DNA exhibits. For full credit, each individual must turn in four completed rubrics.
- Relevant Conclusion Questions 3.1.1
    - Explain how you would determine that each base is 3.4 angstroms along the z-axis.
    - How many hydrogen bonds are between G and C versus between A and T? If your model does not reflect the correct number of hydrogen bonds, what changes need to occur in order to properly display your DNA Model?

**3.1.2 Assessment**

- Students must trace the path of infection for each patient, draw out a flow chart (*Outbreak* style), and label unknown or speculative pathways with question marks. For each patient, the students must write out the primary evidence that brought them to their conclusion. In the final report, the students will: identify pathogen and path of infection for each patient, explain evidence for pathogen identification, and include recommendations for prevention of similar scenarios.
- Relevant Conclusion Questions 3.1.2
    - What techniques are necessary to attain an uncontaminated DNA sequence that can be compared to known data genetic bases by a forensic scientists or a pathologist?
    - How do you compare DNA sequences?
    - Why is bioinformatics the future of biotechnology?
    - What is more definitive in pathogen identification: clinical information or sequence data? Defend your answer.

**3.1.5 Assessment**

- Student teams form a conclusion regarding their analysis of the mock crime scene by presenting the following information to the instructor (in a one page report) and the the class (in a PowerPoint presentation). The one page final report compiled by each group must include the following information:
    - Evidence as to which suspect(s) committed the crime and an explanation of at least four reasons for the team's suspect selection.
    - Documentation as to how the crime was committed and the motive for the crime.
    - Timeline to support your team's conclusion.
    - Identification of blood samples from the NCBI website.
    - Answers to the conclusion questions on the final slides of the PowerPoint.
- Relevant Conclusion Questions3.1.5
    - Why is hair an excellent structure to study for identification purposes?
    - What part of the hair is different from species to species?
    - What other ways can blood be used as forensic evidence?
    - What is *bioinformatics* and how does engineering play a role in this area?

**3.1.6 Assessment**

- An oral presentation is given covering the experimental design, sketches, and application of genetic modification. The teams will document results throughout with digital photos or graphic animations that will be incorporated into a PowerPoint presentation.
- Relevant Conclusion Questions 3.1.6
    - What are some beneficial applications of recombinant DNA technology?
    - What genes are found on the pGlo plasmid and what are there functions?
    - How does a genetic engineer distinguish bacteria containing the plasmid DNA from those bacteria lacking the plasmid DNA?
    - How does a genetic engineer determine if the bacterium has truly been transformed?
    - How does heat shock assist in gene insertion?
    - How does electroporation assist in gene insertion?

**3.1.7 Assessment**

- Students will write a proposal for an industrial application of genetic engineering that includes; thumbnail sketches of proposed designs, genetic maps (i.e., plasmid map) of genes and operon involved and approval application for regulatory agencies. The teams will then create an oral presentation that covers the experimental design, sketches, and application of genetic modification. Student teams will document results throughout with digital photos or graphic animations which will be incorporated into a PowerPoint presentation.
- Relevant Conclusion Questions 3.1.7
    - What controls gene expression?
    - How are operons like power switches?
    - What are the current applications of recombinant DNA technology?

# Differentiation:

## Gifted and Talented

Once the students have completed Activity 3.1.6 Genetic Engineering: Making E. coli Glow like Jellyfish, introduce the following steps as a means of viewing the mutated portions of the sequence in 3D. (Dr. Jay Vavra at High Tech High provided this information)

- Go to NCBI website – **http://www.ncbi.nlm.nih.gov/**
- Click on the word *structure* at the top of the menu
- Download Cn3D v4.1
- Click on *Entrez structure*
- Search for *green fluorescent protein*
- Select a structure – it is suggested that the students compare the wild typ of GFP with all of the isolated mutants such as BFP and RFP
- Once the structure is located, click on *View in 3D*

Open the file and begin exploring. The structure can be spun around and viewed from all perspectives, the mutated portion of the sequence can be viewed, and many other creative options are available for the students.

For project 3.1.1 students could create their DNA model using a 3D modeling software and animate the various components. The animation process of 3D modeling lends itself to a reverse engineering opportunity without the destruction of the student models.

When working with gifted and talent students, advanced technology such as PCR, gel electrophoresis, and microarrays can be added.

### Special Education

Creating intentional groups that pair stronger readers and those with attention issues with students who are stronger in these areas really helps the students who need help stay focused on tasks. This works very well if the students or teacher assign specific duties for the particular project. It is even more effective if the student's case manager is involved in the group forming process or task assignment.

Many times at-risk students have difficulty with manipulation of small objects. For this reason students have the choices of using larger objects to make their DNA structures rather than small objects. Paper models the rotate around a shish-ka-bob stick set in a small bowl of plaster-of-paris is also effective.

### English Language Learners

Intentional teams work in situations with ELL students as well. ELL students should be grouped with students that can guide them and may have a common first language. A word wall can be a great asset as students see the new vocabulary on a daily basis and can add to the wall as they learn new words without losing track of the ones that came before.

## Parents and Administration:

### Administrative/Peer Classroom Observation:

| **Students Are:** | **Teachers Are:** |
|---|---|
| web-searching | guiding and leading instruction |
| building models | providing illustrative examples |
| designing solutions | checking designs |
| supporting hypotheses | encourage safety |
| asking questions | |

## Professional Learning Communities

Professional Learning Communities may find it useful to discuss the following questions:

- How can we help students to visualize the processes of replication and protein synthesis?
- To what depth do students need to understand these processes? How will we know they understand it?

The following resources may provide an additional opportunity for reflection and growth on these topics:

Micklos, D.A., and Freyer, G. A.**.** (2003). *DNA science: A first course, second edition.* New York: CHS Press. (ISBN 978-087969636-8).

## Parent Resources:

- Parents can share family histories and traits.
- Students could "survey" their family members of particular traits: tongue rolling, widow's peak, PTC tasting, attached earlobes, etc. The data can be compiled in class the next day. Students will find that dominant traits are not necessary the most common in a population. However, sensitivity must be shown for students who can't get the data from their biological family. When students learn that they have Grandma's eyes and Grandpa couldn't roll his tongue either, then genetics has deep meaning.
- Doing DNA extraction at home will open conversations with parents about what they learned about DNA in their high school biology. Extraction has become very easy with common kitchen items. One such protocol can be found from the Science and Health Education Partnership (Link: http://www.seplessons.org/node/217).

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