Berkeley Engineers and Mentors

The Recipe for Life

Vincent Lee | Spring 2022

Field(s) of Interest: Biology, Genetics

Brief Overview (1-3 sentences):
Each cell in our body contains DNA, the genetic material that serves as the "instruction manual" for all living things. The variety of physical traits we see in a population is attributed to the different alleles that different people carry. In this lesson, the mentees will be learning about the structure and components of DNA, how genes and alleles function to provide us with our unique traits, and the research methods that scientists employ when extracting DNA from cells.

Agenda:
- Introduction (5 min)
- Module 1: Double the Helix, Double the Fun (15 min)
- Module 2: Mission: Extraction (25 min)
- Module 3: Hand-Me-Down Genes (10 min)
- Conclusion (5 min)

Teaching Goals/Key Terms:	**Mentor Development Goals:** **Written by MD**
➔ DNA ➔ Double Helix ➔ Nucleus ➔ Extraction ➔ Genes ➔ Alleles	➔ Break It Down! ➔ Background Mindfulness ➔ Celebrating Diversity ➔ Reflecting the Semester

written by MD, not applicable for every lesson

Mentor Development Notes

Written by Jay Kim

Break It Down!

Each of these modules are broken down by a handful of specific vocabulary terms as teaching goals pertinent to the module. Having a simple breakdown of a complex lesson such as this can make it not only easier for our mentees to learn the material but also for us mentors to teach them. The teaching goals can be broken down as pieces of a puzzle, each acting as a theme of the overall module. Or, you can choose to break the teaching goals down by using analogies, helping the mentees to form connections between our complex STEM ideas to the real world in a way that they can easily visualize.

Background Mindfulness

It is important to be mindful that our mentees may not have a “traditional” family and/or household background. One of our modules focuses on genetic lineage. While important to teaching this concept, having awareness of these differences (e.g. single-parent household, same-sex parent houseld, adoptive parents) is critical. Also, it is important to acknowledge the difference between biological sex and gender and what various mentees’ family scenarios may be at home that may not conform to what we typically think of. As mentors, it is our responsibility to choose our words carefully when teaching in order for everyone’s backgrounds to be taken into consideration and respected.

Celebrating Diversity

We’re all almost genetically identical — humans share about 99.9% of DNA with each other! Even with such similarities, we celebrate our diversity based on how we look, act, and behave. The difference of just 0.1% makes each individual unique. Different family structures can result from different genetic inheritances, with several genetic combinations that make us all different. Just because we are all different, however, doesn’t mean that a certain combination is better than the other!

Reflecting the Semester

How have you grown as a mentor this semester? How did your comfort level, confidence, and performance in your teaching change from your first site to your last? What have you learned from your site teaching experience this semester? What have you learned from your site members? At the end of the day, our time with our site members and site mentees are limited — but the lessons, skills, and values we learn are something we can take with us to apply not only in future semesters but throughout our mentoring careers.

Background for Mentors

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Module 1

- DNA
- Nucleotide
- Double Helix
- Bases
- Base Pair

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DNA is the material found in the nucleus of every cell that *carries information that determines how a living thing will appear and function*. For example, DNA will determine our hair and eye colour, whether we are tall or short, etc. Basically, it's the blueprint for all life! It communicates instructions for proteins to be made, that can then be used to carry out the cell's function. Every cell in our body has the same set of DNA, but depending on where the cell is located, it will have different functions and require different DNA segments to be expressed more than others.

DNA has a complex structure made of building blocks called **nucleotides**. The main components of a nucleotide are a **base** (adenine, guanine, cytosine, or thymine), a sugar (deoxyribose), and a phosphate unit.

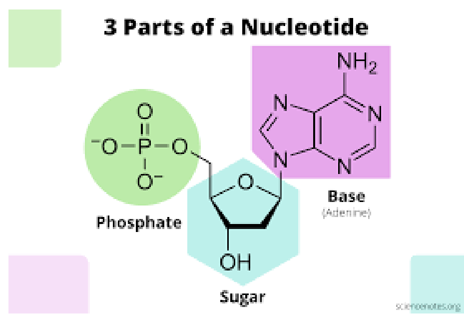

Figure 1: Nucleotide components

The physical structure of DNA resembles a ladder that has been twisted to form a spiral, also known as a **double helix.** The sugar of one nucleotide links together with the phosphate of another nucleotide to form a chain, creating the sugar-phosphate backbone of DNA, like the side rail of a ladder. The nitrogenous **bases** of one nucleotide chain form bonds with the nitrogenous bases of another chain, almost like the rungs of a ladder. It's important to note that adenine (A) can only **base pair** with thymine (T), and guanine (G) can only **base pair** with cytosine (C) *. Mutations can occur where there is a mismatch pairing, which could cause a kink in the DNA and prevent it from being read for instructions.

This double helical shape of DNA has many advantages, such as the fact that it can unwind and have two parent strands where DNA replication can occur. This structure also provides easy access for proteins to scan for instructions, as well as to check for any errors that need to be repaired.

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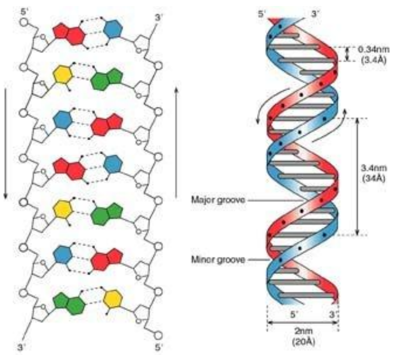

Figure 2: DNA double helix

* Depending on the age level of your site, you can choose to just call the bases A, T, G, and C, but if your mentees are curious you can definitely tell them their names
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Background for Mentors

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Module 2

- Extraction
- Nucleus
- Lysis
- Precipitation

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Now that we have a basic understanding of DNA's molecular and physical structure, let's see it in real life! DNA **extraction** is a modern research method that scientists use to isolate and purify DNA from organisms. Once extracted, the DNA can be used in many different ways. For example, scientists can isolate DNA from organisms with desirable traits (ex: pesticide resistance, glow-in-the-dark capabilities, disease immunity, etc.) and transplant it into another organism to express the desirable trait. DNA extraction is also important for crime scene investigations, vaccine production, therapeutic cloning, etc.

There are three main steps to consider when extracting DNA: **lysis, precipitation,** and purification. The first step, **lysis**, is the act of breaking open the cell and **nucleus**, where the DNA is housed. This can be done physically (ex: grinding, blending, squishing, etc.), chemically (ex: with enzymes that break down membranes, detergents, etc.), or through a combination of both.

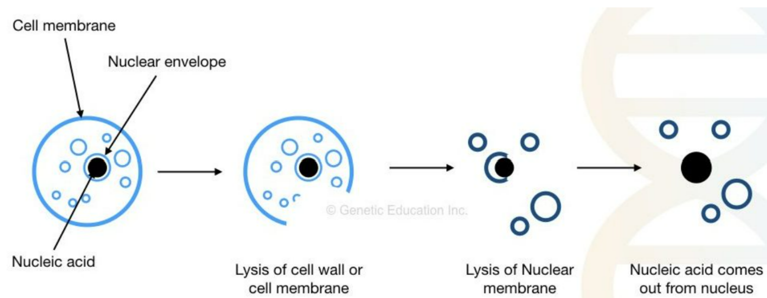

Figure 5: Lysis of the cell membrane and nuclear membrane to release nucleic acid

Now that the DNA is free from the nucleus, we can isolate it through the second step, **precipitation**, which is the process of causing an insoluble solid to emerge out of a solution. We can do this by manipulating the solubilities of the components in our solution. Recall in the first module that each building block of DNA contains a phosphate unit. Phosphate is negatively-charged and causes DNA to be polar and very water-soluble. Adding positively-charged sodium ions (salt) will neutralize these negative phosphates and cause the DNA to become less water-soluble. Adding an alcohol layer will then cause the DNA to become visible clumps and emerge out of the solution, since DNA is insoluble in alcohol. We have now precipitated DNA out of our solution!

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	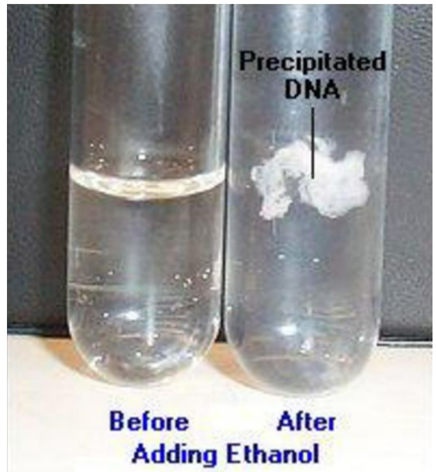 **Figure 6:** Adding alcohol causes DNA to precipitate out of our solution Finally, in the last step, purification, our DNA extract is rinsed in alcohol to remove any cell debris and unwanted material. It can then be dissolved in water to be stored for later use, such as for PCR, sequencing, etc. Because our mentees will simply be removing the precipitated DNA to observe, we will not be purifying our DNA.

Background for Mentors

Module 3

- Chromosome
- Gene
- Allele
    - Dominant
    - Recessive
- Genotype
- Phenotype

Once scientists extract DNA from an organism, they can do many things, like sequencing to figure out the order of bases and what they might encode for. Because DNA has to contain so much information, it is a very long structure. In fact, if you uncoiled a strand of DNA in a single human cell, it would reach 2 meters in length. In order to pack all of that DNA into a tiny nucleus, DNA is wrapped and condensed into structures called **chromosomes.** The chromosome structure also helps facilitate an efficient replication process. Humans have 23 pairs of chromosomes, one set from each parent (46 in total), but certain genetic conditions could cause someone to have different numbers of chromosomes.

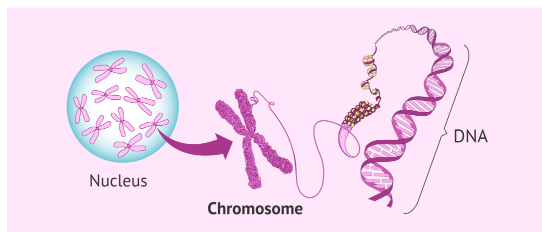

Figure 3: DNA condensed into chromosomes

Genes are the segments of DNA that code for proteins, which carries out the cell's function. We inherit genes from our parents, similar to a recipe that has been passed down from generation to generation. If a gene is a recipe, then **alleles** are different versions of that recipe. For example, a gene encoding eye colour could have a "brown eye allele" or a "blue eye allele". Typically, for each trait, we inherit one allele from each parent. If they are the same alleles, the organism is homozygous for that gene; if they are different alleles, the organism is heterozygous for that gene.

Alleles are also categorized as either **dominant** (usually associated with a capital letter) or **recessive** (lower-case letter). For example, if the brown eye allele was dominant and the blue eye allele was recessive, we could label them as "B" and "b", respectively. If you had the alleles BB (homozygous dominant), you would physically express the dominant trait, brown eyes. If you had the alleles Bb (heterozygous), you would still express the dominant trait, which would be brown eyes. If you had the alleles bb (homozygous recessive), you would express the recessive trait, blue eyes. Your genetic makeup, in other words, the allele versions that you carry, is known as your **genotype**, and the physical trait that you express is known as your **phenotype.**

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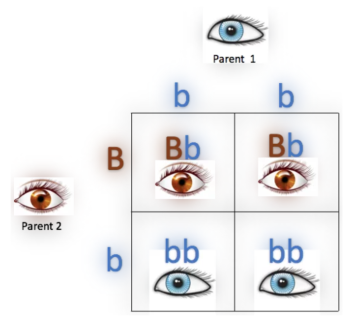

Figure 4:
BB genotype = brown eye phenotype
Bb genotype = brown eye phenotype
bb genotype = blue eye phenotype

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Introduction

Concepts to Introduce ● Double Helix ● Genes ● Alleles ● Nucleus ● Extraction	**Current or Past Events** ● The human genome was finally fully sequenced in April 2003. ○ View the timeline of events here: https://www.genome.gov/human-genome-project/Timeline-of-Events ● Colin Pitchfork was the first murderer to be caught using DNA analysis in 1986. ● In 2012, UC Berkeley professor Jennifer Doudna discovered CRISPR-Cas9, which provided cutting-edge technology to editing genes ○ Dr. Doudna was awarded the Nobel Prize in 2020 for her discovery
Questions to Pique Interest ● Why does everyone in this classroom look different from one another? ● How long do you think a single strand of DNA is? ● What provides the information that tells our bodies how to develop and function?	**Inspiring Scientists, Careers, Applications** ● Rosalind Franklin used X-ray crystallography to produce clear images of DNA ○ These images were shown, albeit without Franklin's permission, to James Watson and Francis Crick, who ultimately discovered the double helical nature of DNA ● Gregor Mendel was a botanist who discovered the 3 laws of inheritance using pea plants. ● Possible careers: geneticist, forensic scientist, clinical/laboratory researcher

Module 1: Double the Helix, Double the Fun

In this module, the mentees will learn about the building blocks of DNA, what it's made up of, and the basic structure of DNA. To help with visualizing the structure, the mentees will be making their own origami model DNA's. By the end of this module, the mentees should be able to recognize a double-helix shape and understand which bases pair together.

Teaching Goals

1. **DNA:** genetic material found in the cell nucleus that determines an organism's appearance and function
2. **Nucleotide:** the building block of DNA, consisting of a sugar, phosphate, and base
3. **Double Helix:** the twisted ladder structure that DNA takes on
4. **Bases:** the "variable" part of DNA (A, T, G, or C) whose specific sequences/order code for an individual's traits
5. **Base Pairing:** the mechanism through which the bases on one strand of DNA binds to the bases on another strand to form a double-stranded structure

Tips for Virtual Sites

Make sure to show what your template looks like after each step, so that the mentees can still follow along with you, even virtually. Be specific in your directions for folding.

Materials

Per student

- Template hand-out

Procedure

1. Introduce the topic, explaining what DNA is, what it looks like, why it's important, and its components (recall: Lesson 7, DNA is the *blueprint* of all life)
2. Explain that there are 4 types of bases in DNA and that only certain bases can bind to another (A only binds to T, G to C).
3. Hand out a model DNA template to every student.
4. Fold the template hand-out in half like a "hot dog". Make sure the creases are nice and crisp as that will make the later steps easier (use fingernails to flatten out the creases).
5. Hold the paper so that the diagonal lines are thick and the horizontal lines are thin. Fold the first rectangle segment downwards along the horizontal line, then unfold.

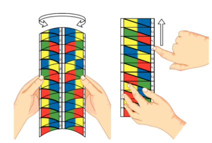


Figure 1: Fold template in half lengthwise.

Figure 2: Fold along the first horizontal line. Repeat until all horizontal lines have been folded.

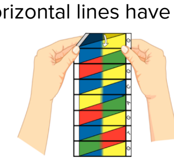


Figure 3: Flip the paper over, then fold along diagonal lines until they've all been folded.

6. Fold the first two segments along the second horizontal line, and repeat until all of the rectangle segments have been folded.
7. Flip the template over so that the horizontal lines are thick and the diagonal lines are thin.
8. Fold along the diagonal line in the first rectangle segment, then unfold. Repeat until all diagonal lines have been folded.
9. Fold the white edge without letters up to make a 90° border.
10. Fold the other edge that has letters down to make a 90° border.
11. Notice that the folded template is starting to twist on its own. Twist and turn the template while pushing the top and bottom towards each other so that the template compresses like a spring.
12. Let go and look at your model DNA!

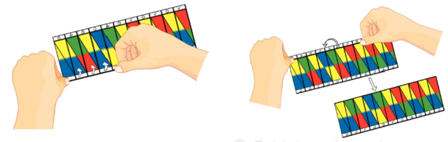


Figure 4: Fold the white edge up and the lettered edge down to make two 90° borders.

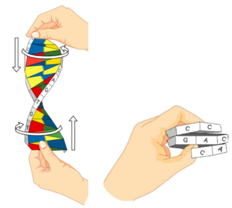


Figure 5: Twist and turn the template until it compresses like a spring.

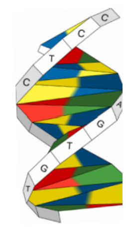


Figure 6: Let go!

Classroom Notes

Take the time to make sure the edges are all folded crisply so that it's easier to twist into a spring. You can use your fingernail or a coin to help. To check for understanding, you can ask the mentees to look at one edge of their model and read out what its complementary bases on the other edge should be without looking at the other side. Younger mentees may not be adept at origami, so practice patience and wait for everyone to finish before moving on to the next step!

Module 2: Mission: Extraction

Now that we have a DNA model, let's see it in real life! Every living thing, from bacteria, to plants, to animals, contains DNA. Sometimes it can be hard to imagine that even our food can contain DNA, so to demonstrate this, we will be extracting DNA from strawberries. Mentees will be learning about the basic steps of DNA extraction and why we use the reagents that we do.

Teaching Goals

1. **Extraction:** the process of selectively removing a compound of interest from a mixture using a solvent
2. **Nucleus:** the "command center" of the cell where DNA is contained
3. **Lysis:** the breakdown of a cell by disrupting its membranes
4. **Precipitation:** the process of transforming a dissolved substance into an insoluble solid

Tips for Virtual Sites

Include the mentees in the activity by asking them questions about why we used certain materials.

Materials

Per group

- 1 resealable plastic bag
- 1 strawberry
- 2 tsp (9 mL) dish detergent
- 1 tsp salt
- ½ cup water
- 2 plastic cups
- 1 coffee filter
- ½ cup rubbing alcohol
- 2 pipettes
- 1 toothpick

Procedure

1. Place mentees into groups of 4.
2. Have **mentee 1** place one strawberry into a plastic bag and mash for 2 minutes to completely crush. *This is our lysis step of extraction, as we crush the strawberries to release the nuclei from the cells.*
3. Once mentee 1 is done mashing, have **mentee 2** add 2 tsp of our prepared extraction liquid (2 tsp detergent, 1 tsp salt, and ½ cup water) in a plastic cup to make your extraction liquid. *The detergent will further break down cell and nuclear membranes to release the DNA. The salt neutralizes the negatively-charged DNA.*
4. Have **mentee 2** continue mashing again for another minute. **Avoid making soap bubbles.**
5. Let **mentee 3** place a coffee filter on another plastic cup and pour the contents of the plastic

Figure 1: Remove the leaves

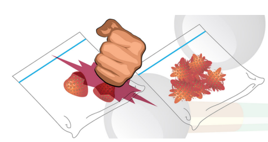


Figure 2: Place the strawberries in a plastic bag and mash

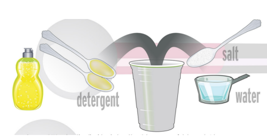
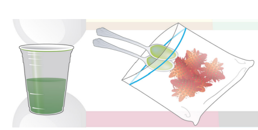


Figure 3: In a separate cup, mix the detergent, water, and salt



bag into the filter. Allow liquid to drain into the cup. You can twist the top of the filter to wring out any remaining liquid

6. The **mentor** should then use a pipette to drip alcohol down the side of the cup until you have equal parts strawberry liquid and alcohol. The alcohol should be a distinct layer on top of the strawberry liquid. Do your best to not mix or stir the alcohol with the strawberry filtrate as the DNA should precipitate into the alcohol layer. *Remember that DNA is insoluble in alcohol, which allows it to precipitate out in this layer.*
7. Within a couple seconds, you should notice a white cloudy and stringy substance in the top layer.
8. Have **mentee 4** use a toothpick and carefully fish this substance out. That is your strawberry DNA!

Figure 4: Add extraction liquid and mash again

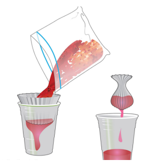


Figure 5: Pour through a coffee filter

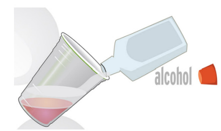


Figure 6: Slowly pour in the alcohol to form a top layer

Figure 7: Watch the DNA clump together and fish it out of the cup

Classroom Notes

Make sure that when mashing the bag after adding the extraction liquid, that you are careful not to form any soap bubbles with the detergent. When adding in the alcohol, use a pipette to drip the alcohol down the sides of the cup as you want to form a distinct layer of alcohol that sits on top of the strawberry mixture. There may be some down time while the mentees mash the strawberries, so use this opportunity to discuss why we're doing the steps that we're doing (Why are we mashing? Why detergent, salt, and water? etc.)

Module 3: Hand-Me-Down Genes

Look at how much DNA is in a strawberry! The blueprint for what makes a strawberry look and taste like a strawberry is found right there on your toothpick. Now, in this module, the mentees will be learning about how DNA is stored in a cell, and how genes are inherited from a source parent material. To illustrate the fact that different combinations of alleles can lead to different traits, and that these combinations of alleles are randomly assorted, the mentees will participate in an activity where they will flip coins to determine the traits of their pet alien.

Teaching Goals

1. **Chromosome:** DNA that has been wrapped tightly into an X shape in order to pack into cell nucleus
2. **Gene:** a segment of DNA that codes for a characteristic
3. **Allele:** different versions of a characteristic that can be coded for
4. **Genotype:** the genetic makeup of an individual
5. **Phenotype:** the physical trait that is expressed

Tips for Virtual Sites

Materials

Per student

- Blank paper
- Designer alien worksheet
- Coin
- Coloured markers/pencils

Procedure

1. Pass out a blank paper, a "Designer Alien Worksheet", a coin, and some coloured markers/pencils to each mentee.
2. On the worksheet, there should be a list of traits that the alien could potentially possess, as well as the allele combinations that lead to each trait (HH, Ht, tt).
3. The mentees will flip a coin twice for each trait. If the coin lands on "heads", they would get the dominant allele, "H", but if the coin lands on "tails", they would get the recessive allele "t". (recall: Lesson 4, *probability of heads/tails is 50%;* allele assortment is by chance)
4. Once the worksheet is completed, you should have a description of the alien's traits.
5. Let the mentees sketch out their pet aliens on the blank paper with coloured markers and have them label each characteristic.

Traits	Dominant (HH)	Hybrid (Ht)	Recessive (tt)
Antennas or not?	Yes	Yes	No
Face shape	Rounded upside down triangle	Circle	Rounded square
How many eyes?	Three	Three	Two

Name of your pet alien: ____________________

Conclusion

End with a discussion on how DNA is found in every living thing, whether it's a piece of fruit, an animal, or a human. Emphasize that everybody has unique DNA, which is why no two people are the same (unless they're identical twins). As this is the last lesson of the semester, you can ask the mentees to think back to some of their favourite lessons and explain why they enjoyed them. Mentees can also reflect on whether they learned anything new about themselves or if they've developed a newfound passion for science!

References

- https://www.yourgenome.org/activities/origami-dna
- http://msbrownclass.weebly.com/uploads/1/2/8/9/12898835/baby_lab.pdf
- https://www.genome.gov/Pages/Education/Modules/StrawberryExtractionInstructions.pdf

Summary Materials Table

Material	Amount per Site	Expected $$	Vendor (or online link)
Extremely Specific Item Name	1 per student		Amazon