

Teacher Preparation Notes for “DNA”¹

This hands-on, minds-on activity includes an easy method for extracting DNA from the archaeon, *Haloflex volcanii*. In addition, students learn or review key concepts about the structure, function, and replication of DNA. For example, students learn that the genes in DNA give the instructions to make proteins, which influence our characteristics. They also learn how the double helix structure of DNA and the base-pairing rules provide the basis for DNA replication. This activity includes multiple analysis and discussion questions and hands-on or online modeling of DNA replication.²

Before students begin the activity, they should have a basic understanding of the structure and functions of proteins. For this purpose, we recommend "Introduction to the Functions of Proteins and DNA" (<https://serendipstudio.org/exchange/bioactivities/proteins>).

We estimate that this activity will require 1½-2 50-minute periods, depending on your students and how much they know about DNA before beginning this activity.

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Learning Goals

In accord with the Next Generation Science Standards³:

- Students will gain understanding of the Disciplinary Core Ideas:
 - LS1.A, Structure and Function, "All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins."
 - LS3.A, Inheritance of Traits, "Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA."
- Students will engage in the Scientific Practice, “Constructing Explanations. Apply scientific ideas, principles and/or evidence to provide an explanation of phenomena...”
- This activity provides the opportunity to discuss the Crosscutting Concept, "Structure and Function. The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials."

¹By Drs. Ingrid Waldron, Lori Spindler, Jennifer Doherty and Mecky Pohlschroder, Department of Biology, University of Pennsylvania, © 2023. These Teacher Preparation Notes and the Student Handout are available at <https://serendipstudio.org/exchange/waldron/dna>.

² An analysis and discussion version of this activity is available at <https://serendipstudio.org/exchange/bioactivities/DNA>.

³ Quotations from <http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf>

- This activity helps to prepare students for two Performance Expectations:
 - HS-LS1-1, "Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life..."
 - MS-LS3-1, "Develop and use a model to describe why structural changes to genes located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism."

Additional Content Learning Goals

- DNA carries the genetic information in all types of organisms. Each DNA molecule contains multiple genes.
- A DNA molecule has two strands of nucleotides wound together in a double helix. Each nucleotide is composed of a phosphate group, a sugar molecule, and one of four different bases: adenine (**A**), thymine (**T**), guanine (**G**), or cytosine (**C**). The phosphate and sugar parts of the nucleotides form the backbone of each strand in the DNA double helix.
- The bases extend toward the center of the double helix, and each base in one strand is matched with a complementary base in the other strand. In accord with the base-pairing rules, **A** pairs with **T** and **G** pairs with **C**.
- Proteins are polymers of amino acids. The specific sequence of amino acids determines the structure and function of the protein. Proteins have many important functions in cells, including protein enzymes that catalyze chemical reactions and transport proteins.
- The sequence of nucleotides in a gene gives the instructions for the sequence of amino acids in a protein. A different sequence of nucleotides in the gene can result in a different sequence of amino acids which can alter the structure and function of the protein. This can result in different characteristics, e.g., albinism vs. normal skin and hair color.
- DNA replication produces two new DNA molecules that have the same sequence of nucleotides as the original DNA molecule; thus, each of the new DNA molecules carries the same genetic information as the original DNA molecule. During DNA replication, the two strands of the original DNA double helix are separated and each old strand is used as a template to form a new matching DNA strand. The enzyme DNA polymerase adds nucleotides one-at-a-time, using the base-pairing rules to match each nucleotide in the old DNA strand with a complementary nucleotide in the new DNA strand.

Supplies and Preparation for DNA Extraction

In the following, we have described the amount of supplies needed if each student does his or her own DNA extraction. If your resources are limited, you can decrease the amount of supplies needed by having each group of students do a single DNA extraction; if you decide to do this, you will need to make appropriate changes to the instructions on page 2 of the Student Handout.

- *Haloferax volcanii*. We have chosen the halophile, *Haloferax volcanii*, for this activity because it is harmless and DNA extraction from halophiles is particularly easy. Moreover, because the agar for growing *Haloferax* has a very high salt concentration, very few microorganisms and no pathogens will grow on this agar, so you do not have to observe sterile procedures and the plates may be disposed of without special precautions.

To obtain *Haloferax volcanii*, please write Dr. Mecky Pohlschroder (pohlschr@sas.upenn.edu) with your request. She will send you a culture-soaked filter disk that can last for a couple of weeks. Use forceps to hold the filter disk and spread it across an agar plate. (Instructions for preparing and storing the agar plates are given on pages 3-4.) The *Haloferax* should grow for approximately 2-3 weeks at room temperature (or 3-5 days at 40-45°C if you have an

incubator⁴). If you want to keep the *Haloferax* for more than 6 months, you should transfer the *Haloferax* to a new plate or plates every 6 months.

The culture plate you will grow from the disk you will receive will provide enough *Haloferax* for you to prepare at least 20 plates for classroom use. Each plate for classroom use should provide enough *Haloferax* DNA for 4 students. Use a Q-tip or a spreader to transfer the *Haloferax* from the agar plate with *Haloferax* to the new agar plates. Rub your spreader gently on the plate with *Haloferax* and then spread the *Haloferax* onto the new plates. Make sure to cover the whole of each new plate.

The plates should be stored in a plastic bag (to prevent drying out) upside down with the lid on the bottom (to prevent moisture from accumulating on the agar). Leave the plates for approximately 2-3 weeks at room temperature (or 5 days at 40-45°C if you have an incubator). Once the plates turn red, the *Haloferax* are in a stationary phase; it is best to use the plates for the student activity within 4-6 weeks after that (or up to 8-10 weeks if you keep the plates in the refrigerator).

If you want the *Haloferax* to grow relatively quickly, you should follow the instructions in footnote 4 for a relatively cheap and simple way to make an incubator. If you have an incubator, you will need 6-10 days (after you receive the *Haloferax* disk) to grow enough *Haloferax* for up to 80 students (4 students each x 20 plates). If you will be using this activity with more than 80 students, you will need to use the initial culture plate to grow multiple *Haloferax* plates, and then use these plates to prepare the number of plates equal to the number of 4-person student groups in your classes. If you have an incubator, this will require 9-15 days. If you do not have or make an incubator, the wait times will be much longer (4-6 weeks for up to 80 students or 6-9 weeks for more than 80 students).

- Agar plates. For each class, the number of agar plates you will need equals the number of groups of four students in that class. You may also want additional plates to grow the *Haloferax* for future use. You can purchase petri dishes (diameter = 100 mm and height = 15 mm) and make your own agar, as described below.

You can make suitable agar medium using one of the following recipes. (The *Haloferax* will grow a little bit better on the second recipe.) You will be able to pour three plates per 100 mL of H₂O.

Table 1. Agar recipe using mainly ingredients that can be obtained from a grocery store

Ingredient	g/100 ml of H₂O
Bacto™ Tryptone, Pancreatic Digest of Casein by Becton, Dickinson and Company	0.5
Difco™ Agar, Granulated, Solidifying Agent by Becton, Dickinson and Company	1.5
Morton Salt without Iodide	15
Relief MD Epsom Salt (Unscented)	5
Nu-Salt by Cumberland	1.0
Regular Strength Antacid- Peppermint Flavor Calcium Rich- Shoprite Brand: Active Ingredient: Calcium Carbonate 500 mg (TUMS)	Crush half of the calcium pill with mortar and pestle

⁴ An incubator is optional, but helpful. You can make a suitable incubator from a Styrofoam cooler (~30 cm high and 30 x 45 cm area at the top) with the bottom part lined with a large heating pad (~30 x 59 cm) and something like a tissue box on top of the heating pad to serve as a support for the plates. Do not let the temperature get above 45°C since this will inhibit the growth of *Haloferax*.

or Table 2. Laboratory grade agar recipe (Tripepi et al. 2010⁵)

Ingredient	g/100 ml of H₂O
Bacto™ Tryptone, Pancreatic Digest of Casein by Becton, Dickinson and Company	0.5
Bacto™ Yeast Extract, Dickinson and Company	0.3
Difco™ Agar, Granulated, Solidifying Agent by Becton, Dickinson and Company	1.5
NaCl	12.5
MgCl ₂ .6H ₂ O	4.5
MgSO ₄ .7H ₂ O	1.0
KCl	1.0
CaCl ₂ .2H ₂ O	0.134

While stirring, carefully bring the water, tryptone and agar (for Laboratory grade recipe, also the yeast extract) to a boil in a flask that is at least twice the volume of the water to avoid superheating. Once the agar is completely dissolved, add the salts and return to the hot plate. When this medium is boiling, quickly remove it from the hot plate to prevent the liquid from boiling over. Repeat the process of bringing the agar to the boiling point and removing it from the hotplate at least three times until the mixture appears clear and the salt is completely dissolved. At this point any salt-loving microorganisms that were associated with the salt should have been killed. Stirring continuously at slow speed, let the media cool down to 50-60°C before pouring the plates. Use at least 30 ml per plate, so the plates will not dry out while the *Haloferax* are growing.

After you pour the plates, they should be stored upside down in plastic bags and kept in a refrigerator until you're ready to grow the *Haloferax*. Because of the high salt concentration of the agar, potentially infectious organisms cannot grow on these plates so they may be disposed of without special precautions.

- 1 mL transfer pipettes (2 per student group)
- Q-tips or spreaders (1 per student group; spreaders can be washed and reused; possible source <https://www.fishersci.com/shop/products/fisherbrand-l-shaped-cell-spreaders-2/p-4249846?xrefPartType=To&fromPartNum=50403863&toPartNum=14665231&xrefEvent=&savings=0.00>)
- Spooling sticks to pull out DNA (preferably 1 per student in your largest class, but at least 1 per student group in your largest class; <https://www.fishersci.com/shop/products/fisherbrand-plain-tipped-applicators-3/23400102?matchedCatNo=23400102>; or you can use the blunt end of barbecue sticks)*
- Test tubes (1 for each student in your largest class; 12 x 75 mm or a little larger)*

*These will need to be washed and set out to dry for reuse in each class.

- Something to hold a test tube upright during the DNA extraction (e.g. a test tube rack for each student group in your largest class; you may also want to have a tub to collect dirty test tubes)
- Chilled 70-95% isopropyl or ethyl alcohol (1 mL per student; you will probably want to have available a tub of ice, freezer, or refrigerator to keep the alcohol chilled and small beakers or jars to hold small amounts of alcohol for student use)

⁵ Tripepi, M. S. Imam and M. Pohlschroder. *Haloferax volcanii* Flagella Are Required for Motility but Are Not Involved in PibD-Dependent Surface Adhesion[†]

Supplies and Preparation for Modeling DNA Replication

- nucleotide pieces – A template for making enough nucleotide pieces for nine students or pairs of students is provided on the last page of these Teacher Preparation Notes. After you photocopy enough copies for the number of students you have, you can:
 - precut each page in nine parts and provide your students with scissors as well as tape or
 - recruit student helpers to precut each page to make 9 packets of 10 nucleotides each.
- tape

If you prefer, you can use the online [DNA Replication Simulation](#). This simulation will allow the students to move each individual nucleotide from the table at the bottom of the page to the appropriate location in the drawing of the separated DNA strands.

Instructional Suggestions and Biology Background

General

To maximize student learning and participation, we recommend that you have your students work in pairs or small groups to answer each section of related questions. Student learning is increased when students discuss scientific concepts to develop answers to challenging questions. After your students have answered each section of related questions, we recommend that you have a class discussion to probe student thinking and help students develop a sound understanding of the concepts and information covered. In order to consolidate accurate understanding, you may want to offer students the opportunity to prepare revised versions of their answers to key questions.

In the Student Handout, numbers in bold indicate questions for the students to answer and letters in bold indicate steps in the extraction procedure for the students to do.

If you use the Word version of the Student Handout to make changes for your students, please check the PDF version to make sure that the figures and formatting in the Word version are displaying correctly on your computer.

A key for the Student Handout is available upon request to Ingrid Waldron (iwaldron@upenn.edu). The following paragraphs provide additional instructional suggestions and background information – some for inclusion in your class discussions and some to provide you with relevant background that may be useful for your understanding and/or for responding to student questions.

Introduction

Question 1 will help students recall their previous learning about DNA, and a class discussion of their answers will help you to understand your students' current knowledge of DNA, including any misconceptions they may have.

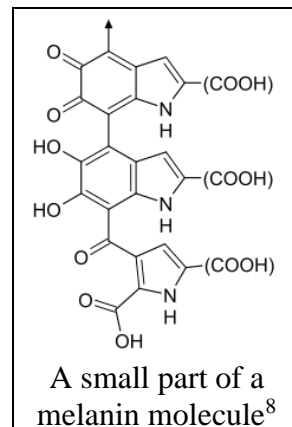
To ensure student understanding in this introductory activity, the Student Handout includes multiple simplifications. For example, the definition of a gene on page 1 of the Student Handout ignores multiple complexities, including the facts that many genes code for more than one polypeptide and many other genes code for RNA that has different functions from mRNA (e.g., ribosomal RNA and regulatory RNA).

You will want to be sure that your students understand that DNA carries the genetic information in all types of organisms, and the basic function and structure of DNA is similar in all types of organisms.

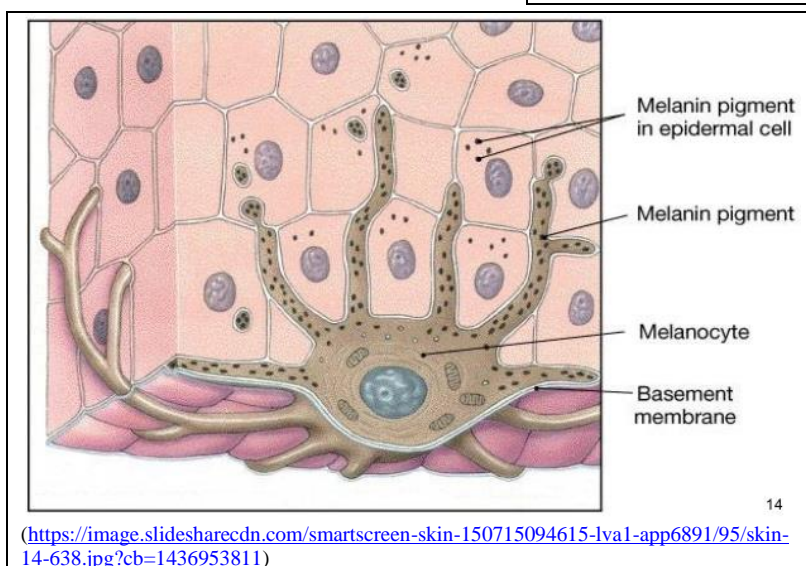
Question 2 discusses genes that are crucial for the cells to survive; if a version of one of these genes gives instructions to make a nonfunctional version of the protein, this would result in cell

death.⁶ In contrast, the table near the bottom of page 1 of the Student Handout describes an example of a gene that is not crucial for cell survival; therefore, an allele of this gene that codes for a nonfunctional version of the protein enzyme is not lethal and instead can result in albinism.⁷

The allele for albinism codes for a defective enzyme (tyrosinase) for producing melanin, a dark pigment that protects skin cells' DNA from the damaging effects of the sun's UV radiation. In the most common form of albinism, the defective enzyme for producing melanin not only results in albino skin and hair color, but also affects the appearance and function of the eyes.



Melanin is produced in melanosomes inside melanocytes and transported into the epidermal cells in the outer layers of the skin. A good explanation is provided in the short video, “How We Get Our Skin Color”.⁹



After question 3 you may want to ask your students the question shown below. This question will alert your students that skin color is influenced by other genes (e.g., genes that influence how much melanin is made) and environmental factors (e.g., sun exposure which can result in increased production of melanin).¹⁰

4a. Based on what you know about human skin color, are these two versions of a gene the only factors that influence skin color? no ___ yes ___

4b. Explain your reasoning.

⁶ Although DNA with genes is required to give the instructions for making proteins, not all cells have DNA. For example, mature red blood cells do not have DNA because they have ejected their nuclei after hemoglobin and other proteins have been synthesized.

⁷ Since this allele is recessive, a person would be albino only if both copies of the gene coded for a nonfunctional version of the protein enzyme; this complexity is not discussed in this learning activity, but instead is discussed in “Genetics” (https://serendipstudio.org/sci_edu/waldron/#genetics) or “Introduction to Genetics – Similarities and Differences between Family Members” (<https://serendipstudio.org/exchange/bioactivities/geneticsFR>).

⁸ <https://upload.wikimedia.org/wikipedia/commons/thumb/3/3a/Eumelanine.svg/220px-Eumelanine.svg.png>

⁹ Available at <http://www.hhmi.org/biointeractive/how-we-get-our-skin-color>.

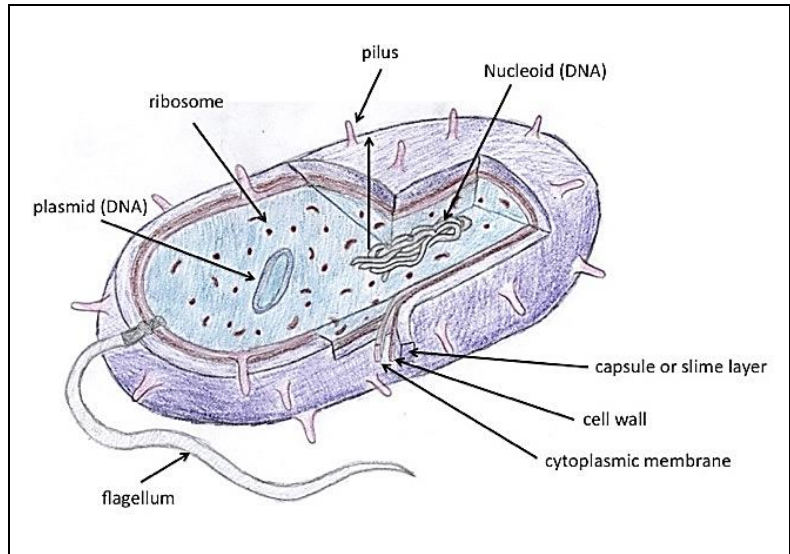
¹⁰ These points are developed in “Were the babies switched?” (https://serendipstudio.org/sci_edu/waldron/#blood).

Further information about albinism is available at <https://medlineplus.gov/ency/article/001479.htm> and <https://omim.org/entry/203100>.

DNA Extraction

You may want to briefly introduce students to archaea as single cell prokaryotic organisms.¹¹

Many archaea are adapted to extreme environments such as very high salt concentrations. For example, *Haloferax* cells accumulate high concentrations of KCl to balance the high osmotic concentration of the extremely salty environments where *Haloferax* grows. Many other halophiles accumulate high concentrations of relatively small organic molecules. Other archaea live in a variety of environments such as the ocean, soil, and the human colon. A brief summary of the biology of archaea and *Haloferax volcanii* is available at



<https://sites.google.com/site/molecularbiologyw/home/haloferax-molecular-biology>.

If your students are not yet familiar with osmosis, you can substitute an explanation for question 4. You may also want to demonstrate that the *Haloferax* do not lyse if put in saturated salt solution.

Before your students begin the DNA extraction, we recommend that you show our video which demonstrates the procedure

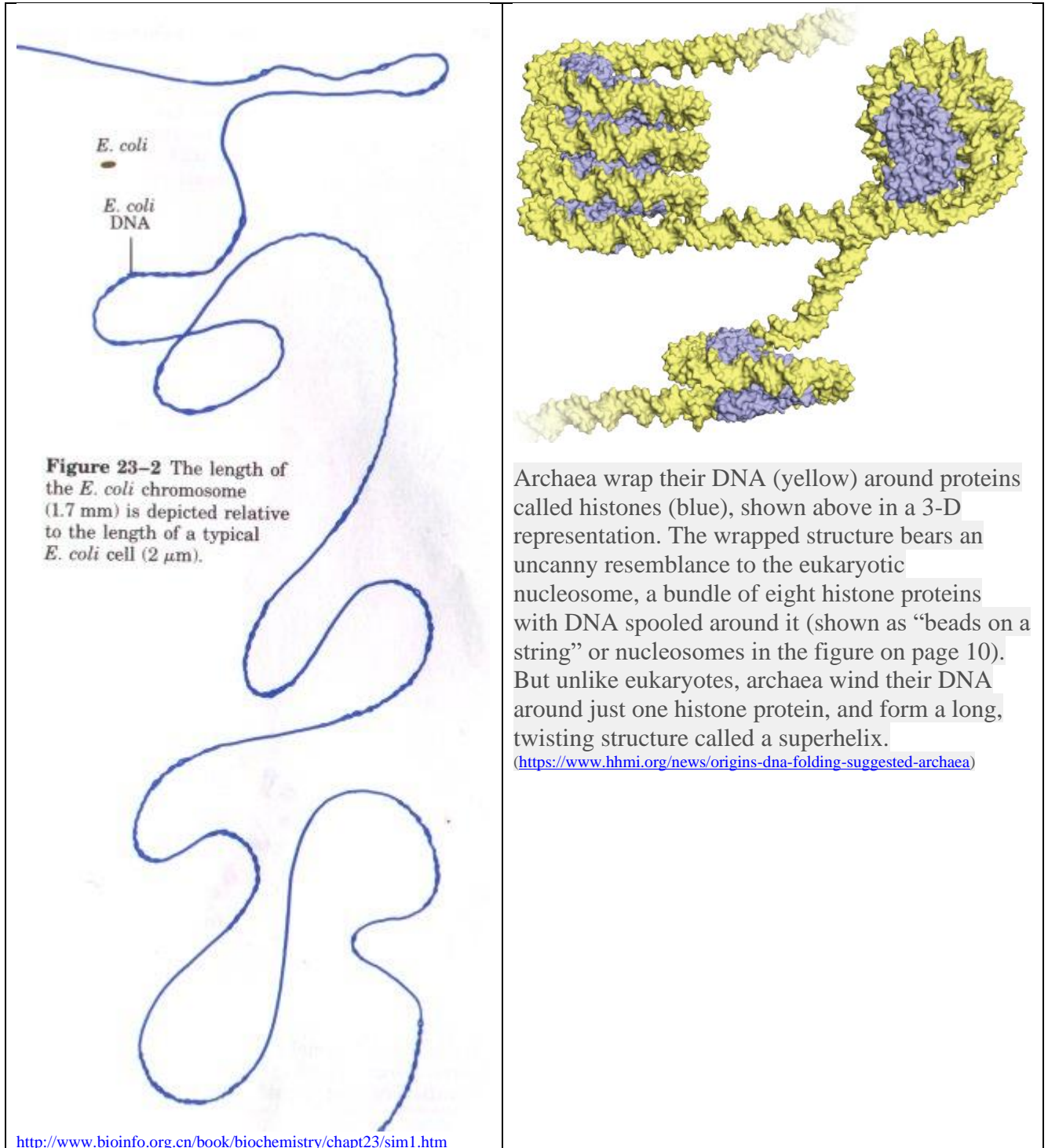
(<https://www.youtube.com/watch?v=Xc1ek1QKEU8&feature=youtu.be>), and/or you can personally demonstrate:

- how to use a pipette to add 5 mL of water on a plate of *Haloferax* and use a Q-tip or spreader to gently move all the lysed cells off the agar surface and mix the lysed cells with the water
- how to tilt the agar plate and use a pipette to suck up 1 mL of the solution with dissolved DNA to put in a test tube
- how to add alcohol.

As your students stir the lysed cells and water, they will be able to see the strands of DNA swirling in the mixture. The students should also be able to see the strands of DNA swirling as they suck the solution into their pipettes. In addition, the students should notice the increased viscosity of the solution; this increased viscosity is due to the very long DNA molecules dissolved in the water. You can use the figure on the bottom half of page 2 of the Student Handout to emphasize how very long the DNA molecule is compared to the cell that contains it. You may also want to use the figures on the next page to help students visualize how very long

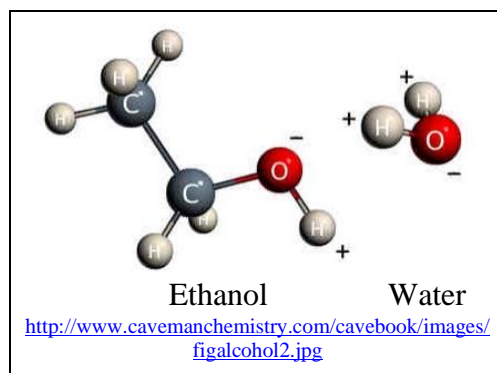
¹¹ This group is sometimes known as Archaeobacteria, but the term archaea is preferred to indicate that this group is a separate domain from bacteria and eukaryotes (<http://www.zo.utexas.edu/faculty/sjasper/images/27T.2.gif>). (Recent identification of Archaea that are phylogenetically very close to eukaryotes and contain many genes previously thought to be specific to eukaryotes have suggested that possibly these two domains should be merged.)

the DNA molecule is compared to a prokaryotic cell and/or to explain how the very long DNA molecule is packed inside a tiny cell.



Each plate of *Haloferax* should have enough DNA solution to prepare a total of four test tubes. After the third test tube has been prepared from each plate, students should add an additional milliliter of water and stir again so the fourth student can pipette up 1 mL of solution with dissolved DNA for their test tube.

You may want to explain to your students that cold alcohol helps to precipitate the DNA molecules by reducing the temperature and adding alcohol to the solution of DNA immediately under the alcohol layer. DNA is soluble in water because the negatively charged phosphate groups in the outer backbone of each strand are attracted to the partial positive charge of the H atoms in the polar water molecules. Ethanol has a polar component, but also has a large nonpolar component, so DNA is less soluble in ethanol.



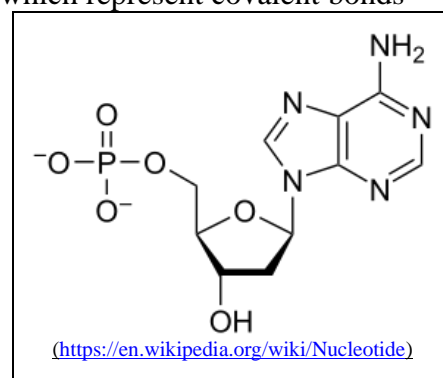
While your students are waiting for the DNA to precipitate, they should read page 3 of the Student Handout and answer questions 5-7. We recommend having a class discussion of this material, before proceeding with the DNA extraction. It will be fine if the wait time after adding alcohol is longer than 20 minutes.

After the 20+-minute wait, when your students are ready to examine the extracted DNA, emphasize that they should first look at the undisturbed test tube. They should see a translucent layer and/or clump where the DNA is located between the original mixture and the alcohol. They may also see strands of DNA stretching up into the alcohol; sometimes the strands of DNA have bubbles on them. The students should tilt the test tube about 45°, put the stick provided ½ inch into the solution, and stir very gently *in one direction only* about 10 times. Then, the students should slowly pull the stick up along the inside of the test tube; they will be able to see the trail of mucus-like DNA stretching behind the stick. Then, the students should gently rub the stick on the edge of the test tube and stretch it outward to see the goopy, elastic strands of DNA.

DNA Structure and Function

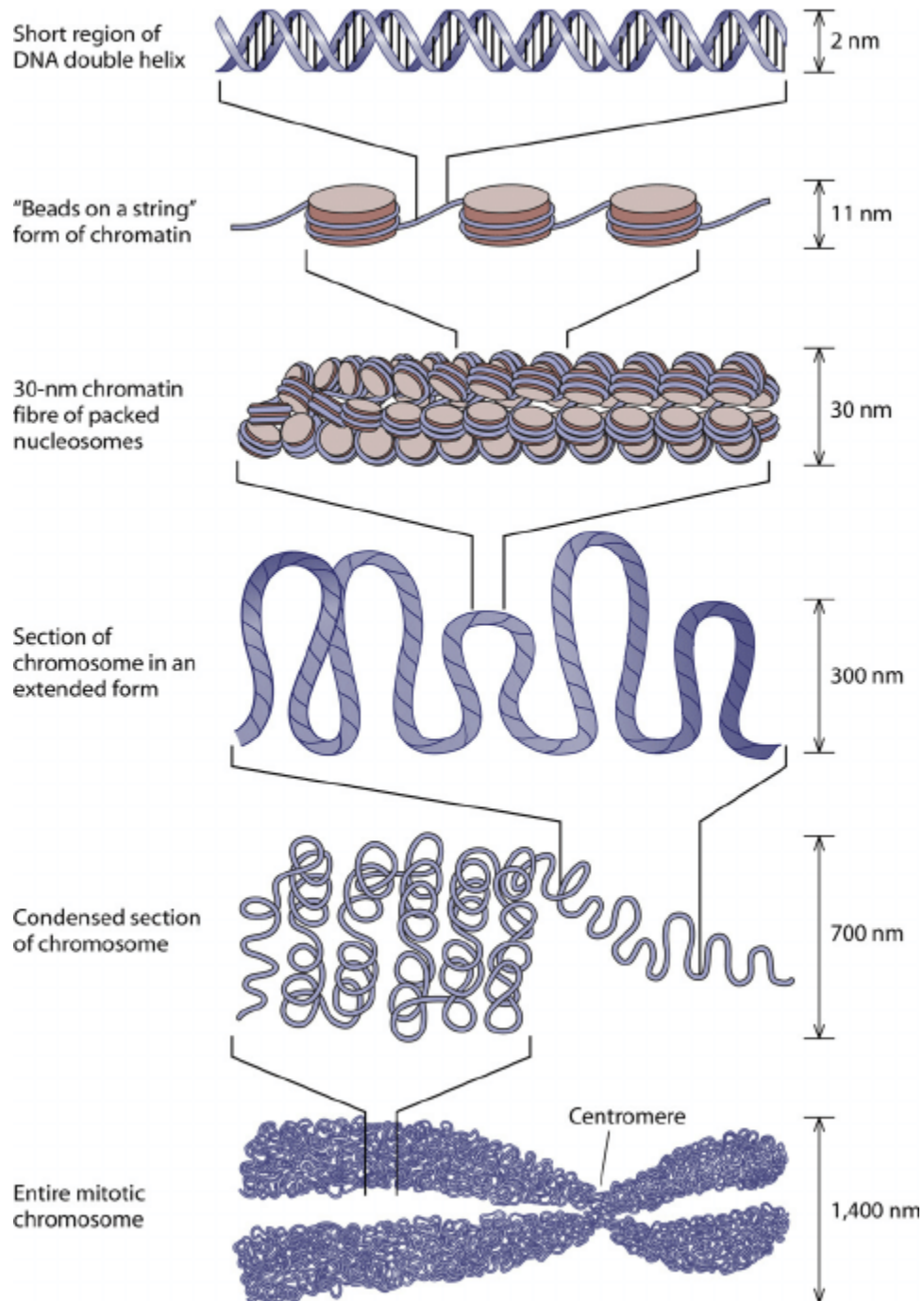
For the right-hand diagram in the top figure on page 3 of the Student Handout, you may want to ask your students about the difference between the solid lines (which represent covalent bonds within each DNA strand) and the dotted lines (which represent hydrogen bonds between the two strands). As shown in the Student Handout, each nucleotide consists of a deoxyribose sugar, a phosphate group and one of four nitrogenous bases. This figure shows additional detail of a nucleotide that contains the nitrogenous base, adenine (A). The nitrogenous bases can accept a positive hydrogen ion, which explains why they are called bases

(<https://www.quora.com/Why-are-adenine-thymine-cytosine-and-guanine-called-bases>).



You may want to explain to your students that DNA stands for deoxyribonucleic acid. Deoxyribonucleic refers to both the deoxyribose sugar in each nucleotide and the fact that DNA is a polymer of nucleotides. You can explain why DNA is an acid, even though it contains bases; the phosphate groups in the backbone of each DNA strand are acidic and this effect dominates, in part because the phosphate groups are on the outside of the DNA molecule and the bases are hydrogen-bonded in pairs on the inside of the DNA molecule.

The DNA molecule in each human chromosome has between 47 million and 249 million base pairs.¹² A DNA molecule is approximately 2 nm in diameter and roughly 3 cm in length. Thus, a DNA molecule is roughly 10 million times as long as it is wide. The structure of eukaryotic chromosomes is highly dynamic (see figure below; The Molecular Biology of the Cell, Fifth Edition). During interphase, most of each chromosome is in the chromatin form. These threadlike chromosomes form loops within the nucleus, which has a diameter of only 5-20 μm in eukaryotic cells.



(https://www.researchgate.net/profile/Kevin_Verstrepen/publication/51196608/figure/fig1/AS:276923784679429@1443035183356/Chromatin-structure-DNA-is-wrapped-around-a-histone-octamer-to-form-nucleosomes.png)

¹² The number of genes per human chromosomes varies from roughly 200 (Y chromosome) to over 3000 (chromosome 1) (<https://www.ncbi.nlm.nih.gov/books/NBK22266/>). Each human cell has 23 pairs of homologous chromosomes. The total number of human genes is estimated to be over 20,000.

Question 7 is crucial for students to understand the function of DNA and why DNA replication needs to preserve the precise sequence of nucleotides. To answer question 7, students should combine information from the table on page 1 of the Student Handout and the bottom half of page 3.¹³ After a class discussion of student answers, you may want to offer your students the opportunity to prepare revised versions of their answers.

To supplement the explanations in the Student Handout, you may want to show your students the 5-minute video, “What is DNA and how does it work?” (<https://www.statedclearly.com/videos/what-is-dna/>).

DNA Replication

Eukaryotic chromosomes change shape during the cell cycle; as a cell prepares for cell division, each chromosome is highly condensed (as shown at the bottom of the figure on page 10 of these Teacher Preparation Notes). The figure in the middle of page 4 of the Student Handout would be more accurate if it showed the chromosomes in a threadlike, more extended form in the initial cell before DNA replication and in the daughter cells produced by cell division; this complexity has been ignored for this introductory learning activity.

To answer questions 8 and 11, students should remember that DNA provides the information to make crucial proteins and the sequence of nucleotides in each gene specifies the sequence of amino acids in each protein, which determines the protein’s structure and function. The rate of errors in DNA replication is extremely low (approximately one in a billion nucleotides). DNA replication is highly accurate, in part because DNA polymerase “proofreads” each new DNA strand for mistakes and backtracks to fix any mistakes it finds.¹⁴

For the DNA replication activity on the top of page 5 of the Student Handout, you will need to provide additional information. See page 5 of these Teacher Preparation Notes.

For question 12, if your students are not familiar with the use of the suffix "ase" to designate an enzyme, you will need to provide that information. If your students would benefit from more scaffolding of question 13, you can use this alternative version.

13a. During DNA replication, the double helix structure, the base-pairing rules, and DNA polymerase work together to make two DNA molecules that are identical to the original DNA molecule. How does the double helix structure help to produce two new DNA molecules that are identical to the original DNA molecule?

13b. How do the base-pairing rules help to produce two new DNA molecules that are identical to the original DNA molecule?

13c. Explain why DNA polymerase is needed for DNA replication.

The description of DNA replication and question 13 provide a good opportunity to discuss the Crosscutting Concept, Structure and Function, “The functions and properties of natural and

¹³ If you want your students to learn more about how the sequence of nucleotides in DNA gives the instructions for the sequence of amino acids in a protein, I recommend the learning activities at <https://serendipstudio.org/exchange/bioactivities/trans> or https://serendipstudio.org/sci_edu/waldron/#trans.

¹⁴ Additional repair mechanisms contribute to the accuracy of DNA copies. Nevertheless, sometimes a mistake is made and not found, and then the mistake can become a permanent mutation. Any daughter cells will have this same mutation. A mutation in a gamete that forms a zygote can result in significant effects, such as muscular dystrophy. (See Mutations and Muscular Dystrophy, <https://serendipstudio.org/exchange/bioactivities/mutation>.) Mistakes in DNA replication during mitosis can contribute to the development of cancer.

designed objects and systems can be inferred from... the way their components are shaped and used, and the molecular substructures of its various materials.

Assessment

After your students have completed the Student Handout, you can assess their understanding of key concepts by having them complete the “DNA Quiz” on page 14 of these Teacher Preparation Notes. After students complete this quiz, you should have a class discussion in which students compare their answers and you provide prompt feedback so they can improve the accuracy and completeness of their answers. This type of active recall with feedback helps to consolidate student understanding and retention of the concepts learned during the activity.¹⁵

Follow-Up Activities and Additional Resources (All the recommended activities are aligned with the [Next Generation Science Standards](#).)

To further develop student understanding of how DNA provides the instructions for protein synthesis and influences our characteristics, we recommend:

– our analysis and discussion activity [From Gene to Protein via Transcription and Translation](#) (<https://serendipstudio.org/exchange/bioactivities/trans>)

or

– our hands-on modeling activity [From Gene to Protein – Transcription and Translation](#) (https://serendipstudio.org/sci_edu/waldron/#trans).

To help students understand how chromosomes are separated during cell division and how genes are transmitted from parents to offspring, we recommend our mitosis activities and our meiosis and fertilization activities:

– https://serendipstudio.org/sci_edu/waldron/#mitosis

or <https://serendipstudio.org/exchange/bioactivities/MitosisRR>

and

– https://serendipstudio.org/sci_edu/waldron/#meiosis

or <https://serendipstudio.org/exchange/bioactivities/meiosisRR>

In [UV, Mutations and DNA Repair](#), students learn about the effects of UV light, mutations and DNA repair on the survival of prokaryotes and the risk of skin cancer. In the first experiment, students evaluate the effects of different durations of UV exposure on survival and population growth of *Haloflex volcanii*. This experiment also tests for photorepair of DNA damage. Students design the second experiment, which evaluates the effectiveness of sunscreen. In addition, students answer analysis and discussion questions that promote their understanding of molecular biology, cancer, and the interpretation of experimental results. (NGSS; https://serendipstudio.org/sci_edu/waldron/#uvmutations)

Additional background information and suggestions for follow-up activities are provided in:

– [Molecular Biology: Major Concepts and Learning Activities](#) (<https://serendipstudio.org/exchange/bioactivities/MolBio>)

– [Genetics – Major Concepts and Learning Activities](#) (<https://serendipstudio.org/exchange/bioactivities/GeneticsConcepts>).

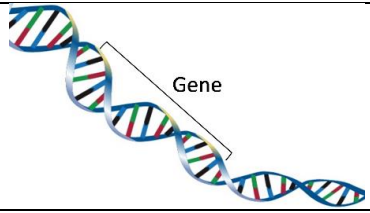
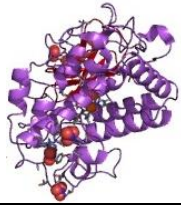

To ensure student understanding of the basics of DNA structure, function, and replication, this activity ignores many complexities. For additional information, see:

- [https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_Introductory_Biology_\(CK-12\)/04%3A_Molecular_Biology](https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_Introductory_Biology_(CK-12)/04%3A_Molecular_Biology)

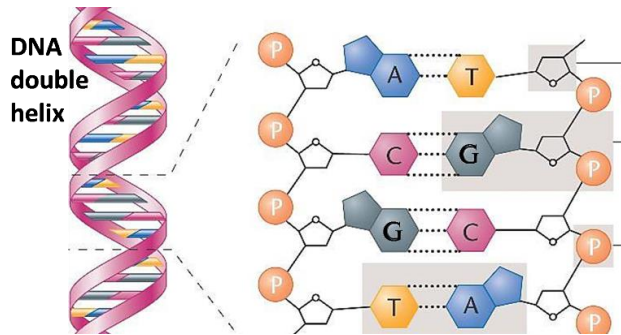
¹⁵ Evidence for the benefits of active recall with prompt feedback is described in <http://www.scientificamerican.com/article/researchers-find-that-frequent-tests-can-boost-learning/>.

- helpful resources available at <https://learn.genetics.utah.edu/content/basics/> and <https://www.biointeractive.org/classroom-resources/teacher-guide-dna>
- videos available at <https://www.biointeractive.org/classroom-resources/chemical-structure-dna> and <https://www.biointeractive.org/classroom-resources/dna-replication-basic-detail>.

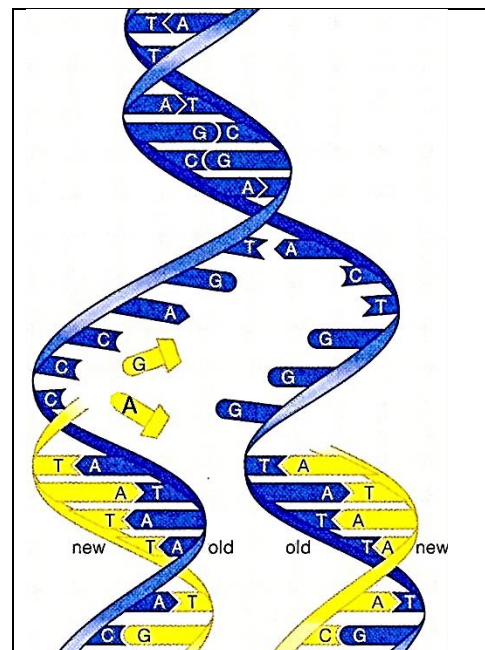
1. Complete this table to describe how two different versions of a gene can result in normal skin and hair color vs. albinism.

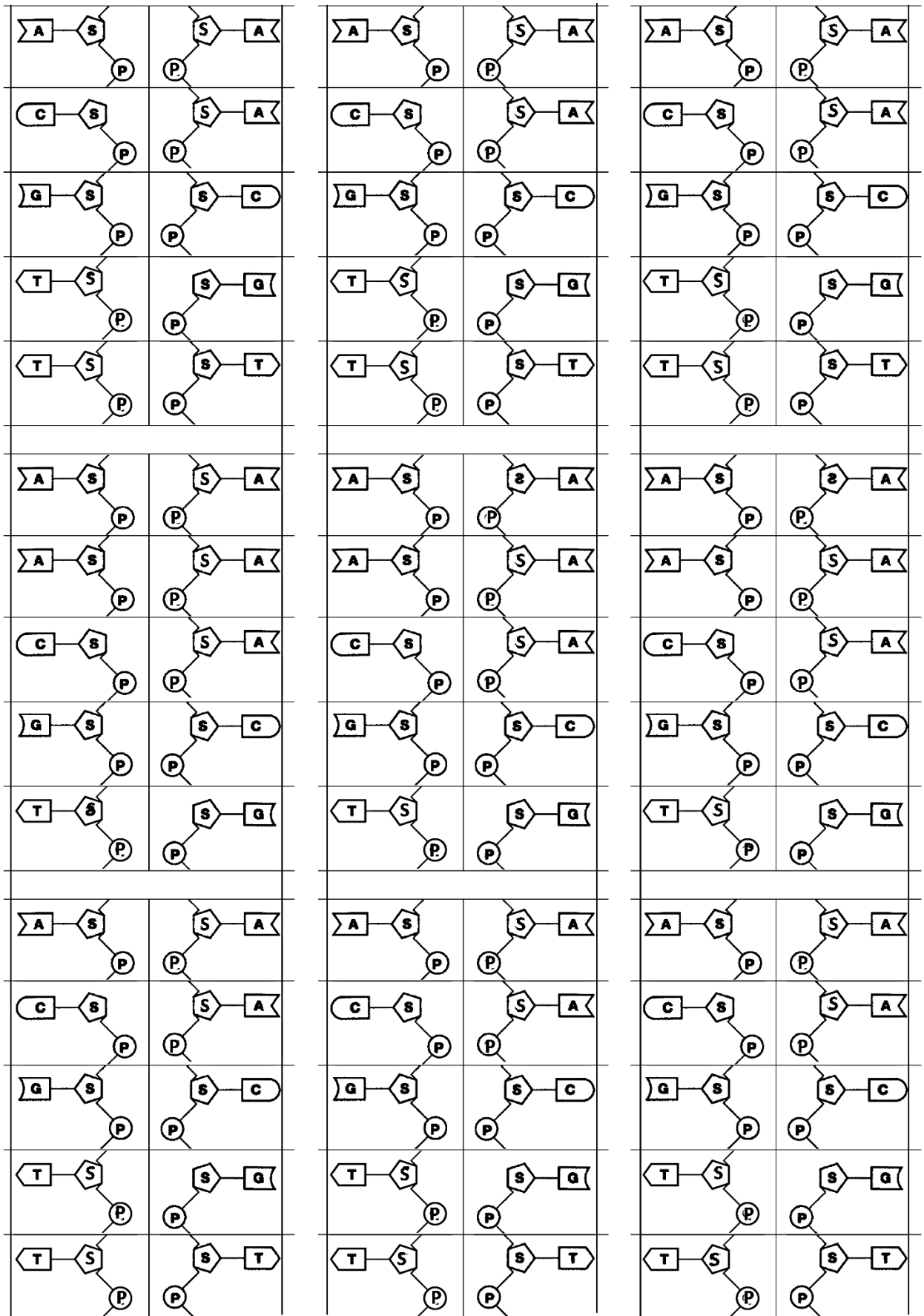
	→		→	
	→		→	
	→		→	Normal skin and hair color
	→		→	Very pale skin and hair = albinism

2. Write sentences and label the figure to describe the structure of DNA.



3. Describe how DNA is replicated.





Nucleotides for Nine Students or Pairs of Students