Key: Yellow highlight = required component

Protein Synthesis

Subject Area(s) (Select from TE Subject Areas)
Biology

Associated Unit

N/A

Lesson Title

Building Proteins.

Header

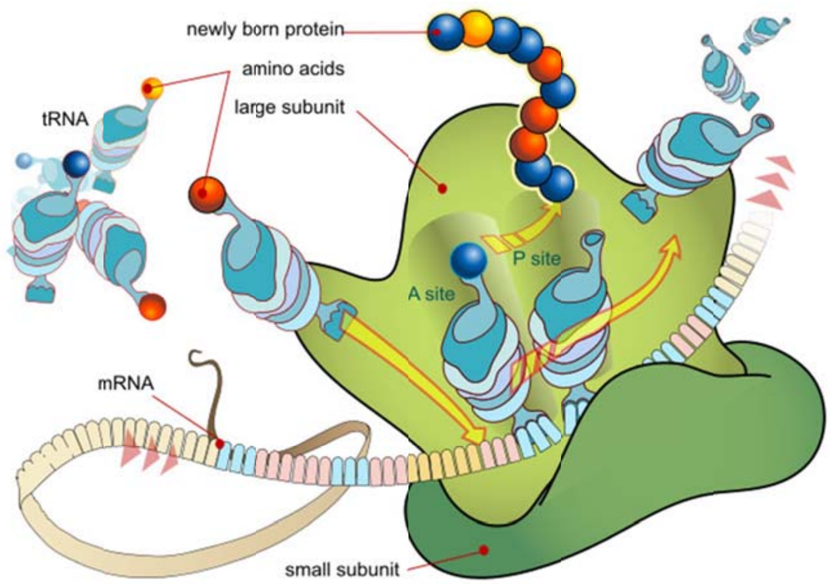

Image 1
Image file: Ribosome.jpg
ADA Description: A ribosome is shown reading a long mRNA strand. The ribosomes call in tRNA molecules containing amino acids. The amino acids from each called tRNA molecule are attached by the ribosome.
Source/Rights: Copyright © 2008 LadyofHats. Wikimedia Commons http://commons.wikimedia.org/wiki/File:Ribosome_mRNA_translation_en.svg
Caption: mRNA transcription taking place in the ribosome leads to the construction of a

Grade Level 9 (9-12)

Lesson # 1 of 1

Lesson Dependency

Time Required 45 minutes

Summary

Students learn about the process of protein synthesis in detail. This covers the entire process from reading the DNA to assembling the necessary amino acids. They will then learn how this process is affected by changes in the DNA, such as those made by genetic engineers.

Engineering Connection

The main principle of genetic engineering involves altering the characteristics of an organisms by making changes to the DNA. These changes to the DNA affect protein synthesis by allowing the organism's cells to produce new or different proteins. The proteins produced allow the genetically modified organism to express different traits than the original. Genetic engineers must understand the process of protein synthesis and know that the changes in a modified organism are a result of the proteins produced by a change in the DNA. This is the fundamental process that explains why DNA modification changes traits.

Engineering Category = 1

Choose the category that best describes this lesson's amount/depth of engineering content:

1. Relating science and/or math concept(s) to engineering
2. Engineering analysis or partial design
3. Engineering design process

Keywords

Amino Acid, DNA, mRNA, Protein, Ribosome, RNA, Synthesis, Transcription, Translation, tRNA

Educational Standards

National and State

Texas, science, 2010, Biology 6 (A): Identify components of DNA, and describe how information for specifying the traits of an organism is carried in the DNA.

Texas, science, 2010, Biology 6 (C): Explain the purpose and process of transcription and translation using models of DNA and RNA.

ITEEA Educational Standard(s)

ITEEA, Standard 14, Grades 9-12, M. The sciences of biochemistry and molecular biology have made it possible to manipulate the genetic information found in living creatures.

NGSS Standard

NGSS, Life Sciences, High School (9-12), 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 through systems of specialized cells.

Pre-Requisite Knowledge

Students should be familiar with the basic biomolecules, here they will need to know the structure of nucleic acids and proteins specifically.

Learning Objectives

After this lesson, students should be able to:

- Describe what is happening during protein synthesis, specifically transcription an translation
- List the different types of nucleic acids and explain their roles in the cell
- Analyze the effect of changes in the DNA

Introduction / Motivation

How many of you have ever put together a Lego set? What about furniture from IKEA or anything that claims "some assembly required"? (Hopefully most students have experience some situation like this). Were you successful in assembling whatever you had? (Yesses, maybe a no) How were you able to turn your project from individual parts into the finished product? Did you have any help, perhaps something provided with the pieces? (Yes, following the instructions.) As it turns out, even your body requires a set of instructions to function properly. These instructions are stored inside your DNA found in every cell of your body.

Speaking of DNA, can anyone think of a superhero who has had their DNA altered? (Lots of possible answers, i.e. Hulk, Spiderman, Captain America) Genetic engineers also change the DNA found in certain organisms to give them certain traits, but unfortunately no super powers. DNA provides the instructions on how to properly assemble all of the proteins that are needed for an organism to function. Proteins are the large biomolecules that perform most of the functions for our cells, so it is very important for them to be assembled correctly. If put together wrong or differently proteins may have completely different functions! Today we will learn how the changes in the DNA can affect the proteins that our cells build by studying the process of *protein synthesis.*

Protein synthesis is process by which proteins are built. Starting with the instructions encoded by the DNA, we will go step by step until we reach the final product: a fully assembled protein. Once you understand this process, you will see the actual details of why genetic engineering works and how one day science may be able to create humans with super powers. Although, the implications of super-humans is a completely discussion on its own.

Lesson Background & Concepts for Teachers

Starting Point: The DNA

DNA (*Deoxyribonucleic acid*) is one type of *nucleic acid* (the other being RNA), a large biomolecule found in every cell of every living organism which encodes the complete genetic information for the organism. In eukaryotes, the DNA is always stored in the nucleus of the cell, and for multi-cellular organisms each cell stores an identical copy of the DNA.

Nucleic acids are biopolymers, meaning they are long molecules built from smaller sub-units. The sub-units are called *nucleotides*. In turn, nucleotides are composed of three groups: a phosphate group, a five carbon sugar (ribose or deoxyribose for RNA and DNA respectively), and a nitrogenous base as shown in the bottom of Figure 1. The phosphates and sugars of nucleotides bond together to form the backbone of the nucleic acid.

There are four types of nitrogen bases for DNA: Adenine (A), Thymine (T), Guanine (G), and Cytosine (C). These nitrogenous bases then form hydrogen bonds with the nitrogenous bases of other nucleotides such that they always form the same "base pairs". That is, Adenine always bonds to Thymine (A-T), and Guanine always bonds to Cytosine (G-C). The hydrogen bonding that occurs is also depicted in the top-right of Figure 1. Once the nitrogenous bases have bonded together, a molecule with two phosphate-sugar backbones is created; this is the DNA molecule shown in the top-left of Figure 1.

Each DNA molecule contains billions of base pairs, and contains the instructions to build every single protein that an organism will need in its lifetime. Therefore, it is also useful to breakdown the DNA structure into one other sub-unit called a *gene*. A gene consists of many nucleotides, but contains the information to build only one protein. This is useful to genetic engineers who often want to add, remove, or change an organism's ability to construct a certain protein. We can use a simple analogy to think of the DNA. The entire DNA molecule represents a complete cookbook and each gene represents and individual recipe in that cookbook; going a little further, the nucleotides would be the letters or words that make up the recipe. Except in this case the cookbook contains the information to build several proteins, not dinner. When one recipe (gene) in this cookbook is accessed, one specific protein will be made.

The Other Nucleic Acid: RNA

Ribonucleic Acid (RNA) like DNA is a long polymer consisting of nucleotides. The difference is that while DNA is found in a double stranded helix (Figure 1), RNA is mostly found as a single strand in nature. Two types of RNA are used in protein synthesis, messenger RNA (mRNA) and transfer RNA (tRNA), whose functions will be described shortly. The second major difference is that RNA does not have any Thymine (T) nitrogenous bases, instead RNA has Uracil (U) bases. Uracil bases essentially take the place of Thymine in RNA and therefore always form base pairs with Adenine (U-A). (This point often takes some reinforcement to remember)

Step 1: Transcription

The first step of protein synthesis is called *transcription*, and this takes place in the nucleus of the cell. *RNA polymerase* (RNAP), an enzyme, first identifies the gene within the DNA which encodes the desired protein (Figure 2). RNAP then breaks the hydrogen bonds between the base pairs in the DNA in order to make a "copy." One backbone of the DNA is referred to as the coding strand, containing the information to build the protein, and the other as the template strand.

The RNAP makes a copy of the coding strand by moving along the template strand and forming base pairs between the template strand and the *messenger RNA* (mRNA) that is created (Figure 3). Recall that the mRNA contains the nitrogenous base Uracil (U) instead of Thymine (T) so the base pairs that are formed by the mRNA will contain Uracil whenever an Adenine base is found in the DNA (U-A) see Figure 4 for an worked out example of transcription from a DNA sequence of nucleotides to an mRNA sequence. Once the copying of the DNA is complete, the mRNA exits the nucleus through the nuclear pore into the cytoplasm, and transcription is complete.

Step 2: Translation

The last step to building a protein is called *translation* and is performed by the ribosomes in the cells cytoplasm. As the mRNA passes through the ribosome, the ribosome "reads" three of the nitrogenous bases at a time; this group of three bases on the mRNA molecule is called a *codon* and contains the information necessary to differentiate which amino acid should be called for (A link to the mRNA codon chart is provided).

When a codon is read from the mRNA, the ribosome brings in a molecule of *transfer RNA* (tRNA) which possesses the matching *anti-codon* and the corresponding amino acid. An anti-codon is a set of three nitrogenous bases found on the tRNA which contain the matching base pairs for the codon on the mRNA, in Figure 5 the anti-codon is the three bases shown at the bottom the tRNA. The tRNA binds with the mRNA inside the ribosome, and the amino acid is linked to the previous amino acid and released from the tRNA. The empty tRNA then moves back into the cytoplasm to be recycled.

Most actual proteins will begin with the mRNA start codon AUG which encodes for Methionine. All proteins will terminate with a stop codon. When the stop codon is reached on the mRNA the protein synthesis has been finished. Technically, at this point the string of amino acids that has been created may instead be referred to as a polypeptide and the once it has reached a folded, fully functional form as a protein.

Figure 4 shows the complete protein synthesis process from DNA to amino acid, with the matching base pairs for the mRNA and tRNA. The complete mRNA codon chart with reading instructions is available under links for reference. Note that this chart tells which amino acid is coded for by the codon in the mRNA, so it is not necessary to determine the base pairs for the anti-codons in this case. Figure 6 is provided as a reference for which nitrogen bases pair together for the different types of pairing discussed (inside DNA, DNA to mRNA, mRNA to tRNA).

Final Product: The Protein

The goal of protein synthesis is to build proteins for cells or organisms to use. These proteins are important because they perform several (most) of the functions necessary for the survival of the cell, but how does changing the proteins that are produced actually effect the cell or organism?

Consider the cells in our own bodies, each cell has the exact same DNA but widely varying functions and forms. This is because different cells use different genes from the DNA code (this is offered with no additional information on gene regulation and cell differentiation as that can encompass and entire lesson itself). These different genes encode for different proteins, and whenever a protein is created, we say that a "trait" has been expressed. This means that by giving cells instructions for different proteins can lead the cells to have different traits. For example, if a genetic engineer were to add the green fluorescent protein (GFP) gene to a cell, the cell would now be able to create GFP and would have the unique trait of glowing green under the right light. Of course, most traits are more subtle and not so easily observable, but the idea remains that by changing the DNA, engineers are able to alter the entire protein synthesis process to have a certain cell or organism create new or different proteins which in turn leads to the expression of desirable traits. So while genetic engineers are physically only changing the DNA, the end result is to actually alter the production of certain proteins.

Image Insert Image # or Figure # here [use Figure # if referenced in text]

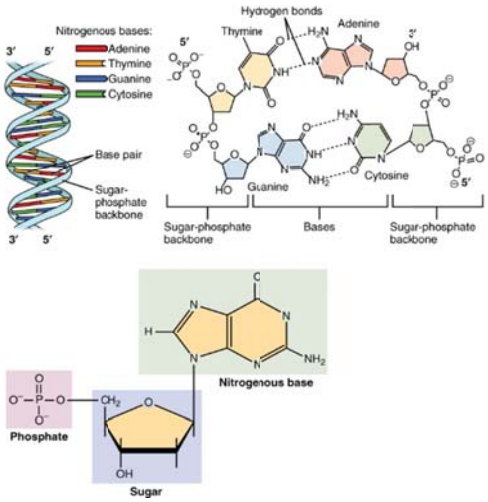

Figure 1

Image file: DNA_Nucleotides.jpg

ADA Description: A DNA molecule. The base pairs of the DNA are magnified to show the hydrogen bonding between bases. The structure of a nucleotide is shown as a phosphate liked to a sugar, linked to a nitrogenous base.

Source/Rights: Copyright © 2013 OpenStax College, Wikimedia Commons http://commons.wikimedia.org/wiki/File:0322_DNA_Nucleotides.jpg

Caption: Figure 1. The structure of DNA and its subunits, nucleotides.

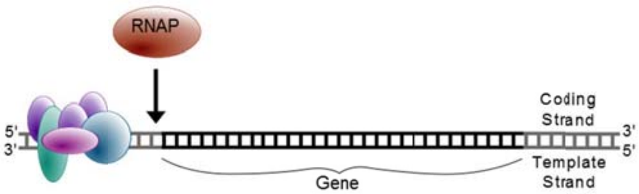

Figure 2

Image file: Figure2.jpg

ADA Description: An RNA Polymerase enzyme approaches a strand of DNA

Source/Rights: Copyright © 2007 Forluvoft, Wikimedia Commons http://commons.wikimedia.org/wiki/File:Simple_transcription_initiation1.svg

Caption: Figure 2. RNA polymerase identifies the gene that will be expressed.

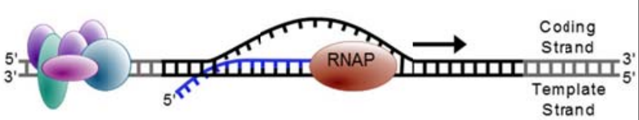

Figure 3

Image file: Figure3.jpg

ADA Description: An RNA polymerase enzyme "unzips" the DNA molecule then follows one of the backbone strands and creates an mRNA. The DNA is "re-zipped" after the polymerase is done.

Source/Rights: Copyright © 2007 Forluvoft, Wikimedia Commons http://commons.wikimedia.org/wiki/File:Simple_transcription_elongation1.svg

Caption: Figure 3. Translation occurs, RNA polymerase matches the base pairs on the template strand of DNA to form an mRNA molecule.

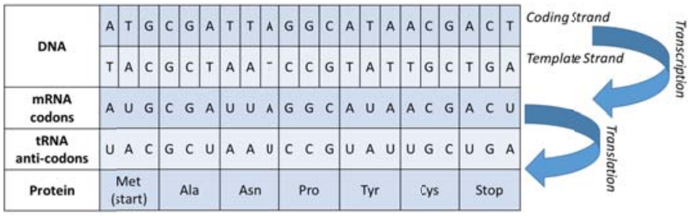

Figure 4

Image file: Figure4.png

ADA Description: A chart shows the DNA sequence of nucleotides, followed by the matching RNA sequence, the matching tRNA anti-codons, and finally amino acids which construct the protein.

Source/Rights: Copyright ©2014 Matthew Zelisko, GK-12 Program, University of Houston

Caption: Figure 4. Transcription and translation illustrated by the matching of base pairs.

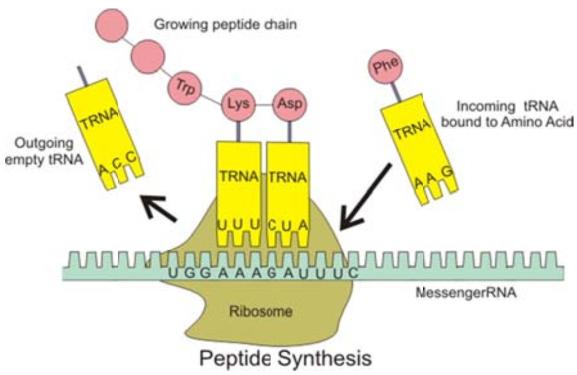

Figure 5

Image file: Peptide_syn.png

ADA Description: The mRNA strand enters the ribosome, where matching tRNA molecules bring in amino acids. The amino acids are linked together and the tRNA is released.

Source/Rights: Copyright ©2009 Boumphreyfr, Wikimedia Commons http://commons.wikimedia.org/wiki/File:Peptide_syn.png

Caption: Figure 5. Translation occurs in the Ribosome, forming a new protein.

DNA to DNA		DNA to RNA		RNA to RNA	
Original DNA Base	*Matching DNA Base*	*Original DNA Base*	*Matching RNA base*	*Original RNA Base*	*Matching RNA base*
Adenine (A)	Thymine (T)	Adenine (A)	Uracil (U)	Adenine (A)	Uracil (U)
Thymine (T)	Adenine (A)	Thymine (T)	Adenine (A)	Uracil (U)	Adenine (A)
Guanine (G)	Cytosine (C)	Guanine (G)	Cytosine (C)	Guanine (G)	Cytosine (C)
Cytosine (C)	Guanine (G)	Cytosine (C)	Guanine (G)	Cytosine (C)	Guanine (G)

Figure 6

Image file: Figure6.png

ADA Description: A chart shows which nitrogenous bases pair together inside DNA, between DNA and RNA, and between two RNA molecules.

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Caption: Figure 6. Matching base pairs between different nucleic acids.

Vocabulary / Definitions

Word	Definition
Amino Acid	Basic building blocks of proteins, there are 21 amino acids that are used in the synthesis of all proteins in eukaryotes
Anti-Codon	Set of three nitrogenous bases found on the tRNA which form matching base pairs with the mRNA codon
Codon	Set of three nitrogenous bases located on the mRNA
DNA	Deoxyribonucleic acid, molecule which contains an organisms complete genetic information
Gene	A subset of DNA, contains the instructions to construct one protein
mRNA	Messenger Ribonucleic acid, nucleic acid molecule whose nitrogenous bases form matching base pairs with the template strand of a DNA

	molecule
Nucleic Acid	Large polymeric biomolecules used to encode genetic information, constructed from sub-units of nucleotides.
Nucleotide	Monomer unit of nucleic acids, composed of a phosphate group, sugar, and nitrogenous base. The nitrogenous bases vary, and the sequence allows the storage of complex information.
Ribosome	Organelle responsible for the construction of proteins, takes information from the mRNA and links the appropriate amino acids to form a protein
RNA Polymerase	Enzyme used for the construction of mRNA during transcription
Transcription	The copying of information from the template strand of DNA onto mRNA by forming matching base pairs between the two nucleic acids. Occurs in the nucleus of a cell.
Translation	The reading of the mRNA by the ribosome to convert the information into a protein using tRNA. Takes place in the ribosomes located in the cytoplasm of a cell.
tRNA	Transfer Ribonucleic acid, nucleic acid molecule which brings the needed amino acid to the ribosome when its anti-codon matches the mRNA codon being read.

Associated Activities

Modeling Protein Synthesis – The students use a simple model to reinforce the process of protein synthesis. They will practice transcription and translation of nucleic acids and learn how proteins are affected by changes in the DNA.

Lesson Closure

Assessment

Pre-Lesson Assessment

Descriptive Title: Biomolecule Structure Review

Verify that the students know the basic structures of nucleic acids and proteins, specifically:

- Nucleic acids and proteins are both polymers
- The monomer unit, or building blocks, of nucleic acids are nucleotides
- The building blocks of proteins are amino acids
- The molecules are formed by linking these building blocks into long chains
- More detail may be covered on the nucleotide structure, but is also available in the lesson

Lesson Summary Assessment

Descriptive Title: Save the Nibblonians Worksheet

Lesson Extension Activities

None

Additional Multimedia Support

mRNA Codon Chart

http://www.shsu.edu/~agr_www/documents/mRNAcodonchart.pdf

References

1. Nucleic Acid. Updated December 16, 2014. Wikipedia, the free encyclopedia. Accessed December 16, 2014. http://en.wikipedia.org/wiki/Nucleic_acid

2. Nucleotide. Updated November 7, 2014. Wikipedia, the free encyclopedia. Accessed December 16, 2014. http://en.wikipedia.org/wiki/Nucleotide

3. Protein. Updated November 28, 2014. Wikipedia, the free encyclopedia. Accessed December 16, 2014. http://en.wikipedia.org/wiki/Protein

4. Transcription (Genetics). Updated December 16, 2014. Wikipedia, the free encyclopedia. Accessed December 16, 2014. http://en.wikipedia.org/wiki/Transcription_(genetics)

5. Translation (Biology). Updated November 23, 2014. Wikipedia, the free encyclopedia. Accessed December 16, 2014. http://en.wikipedia.org/wiki/Translation_(biology)

Attachments

Save the Nibblonians Worksheet

Save the Nibblonians Worksheet (Key)

Other

Redirect URL

Contributors

Matthew Zelisko, Kimberly Anderson

Supporting Program

University of Houston, National Science Foundation GK-12 Program

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant Number 0840889.

Classroom Testing Information

This lesson was taught Fall 2014 at Clear Creek High School, League City, TX for 9th grade regular biology classes. This lesson may be a little complex if done too quickly, our students were taught all of the biomolecule structures, including nucleotide structures well in advance of this lesson to save time. Overall, the students seem to struggle with the concept of protein synthesis so we perform several activities and worksheets to try to help them understand. This is a very important lesson for biology classes, so it does warrant spending some extra time on reinforcement.

Name_____________________________ **Date________________**

Save the Nibblonians

On the far away planet of Eternium lives an intellegent species called the Nibblonians. The climate on Eternium changes very rapidly, so Nibblonian genetic engineers need to continually change the DNA of new Nibblonians to ensure the species does not become extinct. Your job is to help the engineers determine the best traits to help the Nibblonians survive. Luckily, Nibblonian DNA is extremely simple and each trait is the result of small proteins (two amino acids). Begin by decifering the DNA sequence from a present day Nibblonian given below to determine what traits they have now.

DNA	A	A	T	T	G	C	C	C	A	G	T	C	T	T	A	C	G	A	G	C	C	T	A	A
mRNA codons																								
Amino Acids (Proteins)																								
Trait																								

Use the mRNA codon chart to determine the amino acids. Each protein (pair of amino acids) is responsible for the expression of a certain trait in the chart below.

Protein	**Trait**	**Protein**	**Trait**
Leu-Thr	Lungs	*Asn-Ala*	Tall
Met-Trp	Gils	*Cys-Tyr*	Short
Leu-Arg	Hairy	*Arg-Ile*	Green
Gly-Glu	Hairless	*Lys-Asp*	Blue

Now that you and the Nibblonian genetic engineers know what genes are responsible for which traits in the Nibblonians, it is time to help the engineers figure out what DNA needs to be changed to ensure the survival of the Nibblonians. The Nibblonian scientists have determined that there are two possible climate shifts coming on Eternium, and they want you to help figure out which traits will be most important, while making the fewest changes to the current Nibblonian DNA.

Climate 1: Lots of rain, there is no land available for the Nibblonians to live on. Eternium has lots of natural predators in the water, so camouflage is important. Determine what traits should be changed from the original Nibblonians and figure out the new DNA sequence that the genetic engineers will need.

Trait																								
Amino Acids (Proteins)																								
mRNA codons																								
DNA																								

Climate 2: Very cold, snow everywhere. This prevents plants from growing very tall, so food is found close to the ground. Nibblonians like to live together, but don’t want to get lost in the snow. Determine what traits should be changed from the original Nibblonians and figure out the new DNA sequence that the genetic engineers will need.

Trait																								
Amino Acids (Proteins)																								
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Name____________________________ Date_______________

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DNA	A	A	T	T	G	C	C	C	A	G	T	C	T	T	A	C	G	A	G	C	C	T	A	A
mRNA codons	U	U	A	A	C	G	G	G	U	C	A	G	A	A	U	G	C	U	C	G	G	A	U	U
Amino Acids (Proteins)	Leu			Thr			Gly			Glu			Asn			Ala			Arg			Ile		
Trait	Lungs						Hairless						Tall						Green					

Use the mRNA codon chart to determine the amino acids. Each protein (pair of amino acids) is responsible for the expression of a certain trait in the chart below.

Protein	Trait	Protein	Trait
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Gly-Glu	Hairless	*Lys-Asp*	Blue

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Trait	Gils						Hairless						Tall						Blue					
Amino Acids (Proteins)	Met			Trp			Gly			Glu			Asn			Ala			Lys			Asp		
mRNA codons	A	U	G	U	G	G	G	G	U	C	A	G	A	A	U	G	C	U	A	A	A /G	G	A	U /C
DNA	T	A	C	A	C	C	C	C	A	G	T	C	T	T	A	C	G	A	T	T	T /C	C	T	A /G

Climate 2: Very cold, snow everywhere. This prevents plants from growing very tall, so food is found close to the ground. Nibblonians like to live together, but don't want to get lost in the snow. Determine what traits should be changed from the original Nibblonians and figure out the new DNA sequence that the genetic engineers will need.

Trait	Lungs						Hairy						Short						Green					
Amino Acids (Proteins)	Leu			Thr			Leu			Arg			Cys			Tyr			Arg			Ile		
mRNA codons	U	U	A	A	C	G	U	U	A/ G	A	G	A/ G	U	G	U /C	U	A	U /C	C	G	G	A	U	U
DNA	A	A	T	T	G	C	A	A	T/ C	T	C	T/ C	A	C	A/ G	A	T	A/ G	G	C	C	T	A	A