Key: Yellow highlight = required component

Mutations

Subject Area(s)
Biology

Associated Unit

Genetic Engineering

Lesson Title

Unexpected Changes

Header

Image 1

Image file: Tiger.jpg

ADA Description: A picture of a tiger with white fur.

Source/Rights: Copyright © Tony Hisgett, Wikimedia Commons (http://commons.wikimedia.org/wiki/File:White_Tiger_6_(3865790598).jpg)

Caption: The white coat of some tigers is due to a genetic mutation.

Grade Level

9 (7-10)

Lesson #

1 of 1

Lesson Dependency

Time Required

30 minutes

Summary

Students learn about mutations and uncontrolled changes to the genetic code. The lesson introduces the concepts of different types of mutations, to both chromosomes and DNA, and during which process those mutations can occur. The effects of different mutations are also studied as well as environmental factors that may lead to an increased probability of mutations.

Engineering Connection

Genetic engineers have the ability to manipulate the genome of any organism. However, the consequences may not always be beneficial. It is important for these engineers to understand what effects will occur from certain changes to an organism's genome; several of these effects can be seen by studying natural mutations. It is also important to understand how the environment can affect the probability of mutations occurring to help prevent harmful mutations.

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

DNA, Gene, Genome, Meiosis, Mitosis, Mutation, Protein

Educational Standards (List 2-4)

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 (E): Identify and illustrate changes in DNA and evaluate the significance of these changes.

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 (6-8), HS-LS3-2, Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.

Pre-Requisite Knowledge

The students should have a good understanding of how DNA is copied from one cell to another through either meiosis or mitosis. They should also know that changes in the DNA or genes will result in the alteration of proteins which then may or may not cause a noticeable change to an organism's traits.

Learning Objectives

After this lesson, students should be able to:

- **List the different types of mutations**
- **Describe the possible effects of mutations**
- **Explain the role of mutations in genetic syndromes**

Introduction / Motivation

Can someone tell me how Wolverine, from the X-men, got his super-powers? (Answer: He's a mutant, was born with them)

What about the Hulk? (Answer: mutated when exposed to gamma radiation)

And Spiderman? (Answer: mutated when bitten by a radioactive spider)

So we have identified three super heroes that all got some sort of special abilities from mutations. For Wolverine, and any of the X-men for that matter, the powers are caused by a mutation to his DNA or genome before he was even born. The Hulk and Spiderman got their

powers a little differently since the mutations happened later when exposed to radioactivity in some form or another.

Today we will discuss some of the science behind how these mutations could happen. While the super-powers and abilities may be fictional, there is some truth to mutations having a significant impact on someone and also evidence that radiation exposure can lead to an increased rate of mutations. First we will discuss the different types of mutations, then where or how they can occur. We will also talk about some environmental effects and can influence the rate of mutations, and we will finish by looking at some possible effects of mutations. (Cover the remaining information in the background concepts).

Lesson Background & Concepts for Teachers

Types of Mutations

Mutations can be classified several different ways. This lesson will focus on sorting mutations by their effect on the structure of DNA or a chromosome. For this categorization, mutations can be separated into two main groups, each with multiple specific types. The two general categories are *large-scale* and *small-scale* mutations.

Small-Scale Mutations

Small-scale mutations are those which effect the DNA at the molecular level by changing the normal sequence of nucleotide base pairs. These types of mutations may occur during the process of DNA replication during either meiosis or mitosis. There are three possible small-scale mutations that may occur.

Substitution

Also referred to as a "point" mutation, substitutions occur when a nucleotide is replaced with a different nucleotide in the DNA sequence. The most common substitutions involve the switching of Adenine and Guanine (A ↔ G) or Cytosine and Thymine (C ↔ T). Since the total number of nucleotides is conserved, this type of mutation will only effect the codon for a single amino acid.

Deletion

A deletion is the removal of a nucleotide from the DNA sequence. Deletions are referred to as "frameshift" mutations. This is because the removal of even a single nucleotide from a gene will alter every codon after the mutation; it is said that the reading frame is shifted. This is illustrated in Figure 1 for both deletions and insertions. The change in the number of nucleotides will change which ones should normally be read together.

Insertion

An insertion in the addition of a nucleotide to the DNA sequence. Similar to a deletion, insertions are also considered "frameshift" mutations and will alter every codon that is read after the mutation.

Large-Scale Mutations

Large-scale mutations are those which effect entire portions of the chromosome. Some large-scale mutations effect only single chromosomes, others occur across nonhomologous pairs. Some large-scale mutations in the chromosome are analogous to the small-scale mutations in DNA; the difference is that for large-scale mutations entire genes or sets of genes are altered rather that only a single nucleotide of the DNA. Single chromosome mutations are most likely to occur by some error in the DNA replication stage of cell growth, and therefore could occur during meiosis or mitosis. Mutations involving multiple chromosomes is more likely to occur in meiosis during the crossing-over that occurs during the prophase I. Most of these mutations are illustrated in Figure 2.

Deletion

Large-scale deletion is a single chromosome mutation. This involves the loss of one or more genes from the parent chromosome.

Duplication

Duplication is the addition of one or more genes that are already present in the chromosome. This is a single chromosome mutation.

Inversion

An inversion mutation involves the complete reversal of one or more genes within a chromosome. The genes are present, but the order is backwards from the parent chromosome. This is also a single chromosome mutation.

Insertion

Large-scale insertion involves multiple chromosomes. For this type of insertion, one or more genes are removed from one chromosome and inserted into another nonhomologous chromosome. This can occur by an error during the prophase I of meiosis when the chromosomes are swapping genes to increase diversity.

Translocation

Translocation also involves multiple nonhomologous chromosomes. Here the chromosomes swap one or more genes with another chromosome.

Nondisjunction

A nondisjunction mutation does not involve any errors in DNA replication or crossing-over. Instead these mutations occur during the anaphase and telophase when the chromosomes are not separated properly into the new cells. Common nondisjunctions are missing or extra chromosomes. When gametes with nondisjunctions are produced during meiosis, it can result in an offspring with a monosomy or trisomy (a missing or extra homologous chromosome).

Effects of Mutations

The effects of mutations may range from nothing all the way to unviability of a cell. All mutations will affect the proteins that are created during protein synthesis, but not all mutations will have a significant impact. The effects can also be looked at differently between the small-scale and large-scale mutations.

Small-Scale Mutation Effects

Frameshift mutations, insertions and deletions, on genes will have similar effects. In this case, when a nucleotide is added or removed from the DNA sequence, the sequence is shifted and every codon after the mutation is changed as shown in Figure 1. This results in severe alterations to the proteins that are encoded by the DNA which can lead to a loss of functionality for those proteins.

Substitutions, or point mutations, are much more subtle and may have three possible effects. Figure 3 shows how some point mutations may lead to common disorders.

1. *Silent* – the nucleotide is replaced but the codon still produces the same amino acid

2. *Missense* – the codon now results in a different amino acid, which may or may not significantly alter the protein's function

3. *Nonsense* – the codon now results in a "stop" command, truncating the protein at the location where the mutated codon is read, this almost always leads to a loss of functionality of the protein

These mutations may occur anywhere in the DNA. So the effect of the mutation really depends on its location. If the mutation occurs in a gene, the result will be an altered protein, but the mutation can also occur in a nongenic region of the DNA. In the latter case, the mutation will have no effect on the organism.

Large-Scale Mutation Effects

The effects of large-scale mutations are more obvious than those of small-scale mutations. Duplication of multiple genes will cause those genes to be overexpressed while deletions will result in missing or incomplete genes. Mutations that change the order of the genes on the chromosome such as deletions, inversions, insertions, and translocations result in genes that are close together that were previously separated either by a set of genes on the same chromosome or on another chromosome altogether. When certain genes are positioned closely together they may encode for a "fusion protein," that is a protein which would not normally exist but is created by a mutation where two genes were combined. Some of these new proteins give cells a growth advantage leading to tumors and cancer. Astrocytoma, a type of brain tumor, is the result of a deletion which creates a new fusion gene that allows the cells to become cancerous.

Often times, large-scale mutations lead to cells that are not viable. In that case the cell will die due to the mutation. This is especially true with nondisjunction mutations in gametes where entire chromosomes are missing or extra. In Humans, when the gamete from a male (sperm) merges its chromosomes with the gamete from a female (egg), the offspring will receive 23 chromosomes from each parent to form 23 homologous pairs as shown in the karyotype in Figure 4. However, when one of the gametes has a nondisjunction mutation the resulting offspring will end up with only 1 homolog in a pair (monosomy) or with 3 homologs in a pair (trisomy). Most of the time these offspring will not be viable. The ones that do result in viable offspring will possess some noticeable differences due to the extra or missing chromosome; this alteration will lead to a permanent syndrome in the offspring. The most well-known syndrome is

trisomy 21, an extra 21st chromosome, this karyotype is shown in Figure 5; this particular nondisjunction mutation will lead to Down Syndrome.

There are several other syndromes caused by these mutations, the recommended homework is for the students to research some syndrome caused by extra or missing chromosomes and write a short paragraph detailing which chromosome is altered and what the effects are.

What can influence mutations?

Mutations naturally occur over time, this is the underlying cause of evolution. As we can see, evolution is a very slow process with a net benefit to an organism, but there are some environmental factors that may influence or induce additional mutations. These induced mutations often lead to harmful diseases such as cancer.

Exposure to certain chemicals is one environmental factor that may induce mutations in the DNA. Typically anything that is said to be carcinogenic (may cause cancer), has negative side effects on DNA which leads to cancer. This could be anything from the chemicals found in cigarette smoke to those found in meats cooked on the grill. These chemicals belong to a larger class called mutagens, meaning they can lead to changes in genetic material.

Chemicals are not the only types of mutagens that we encounter, there are also physical mutagens, namely radiation. Ultraviolet radiation from the sun can damage genetic material by changing the properties of nucleotides in the DNA. Overexposure to ultraviolet radiation is known to lead to skin cancer. X-rays and gamma radiation are also physical mutagens and forms of ionizing radiation; this means that these types of radiation possess enough energy to remove electrons from atoms, thus forming ions and effecting how different biomolecules will interact. While the typical dose of X-rays during a medical procedure is low, it does marginally increase the cancer risk of the patient.

Alternatively, retroviruses, such as HIV, naturally experience mutations at a much higher rate than other organisms. This can be attributed to the fact that they possess RNA instead of DNA. The process by which RNA is copied and replicated is not a precise as that of DNA. Therefore by the time our immune system has adjusted to fight a virus like HIV, it has already mutated again and the immune system must start over. The mutations in the HIV's RNA lead to alterations in the protein markers on the virus that the immune system targets, and if the target is always changing it is almost impossible for the immune system to remove the virus.

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

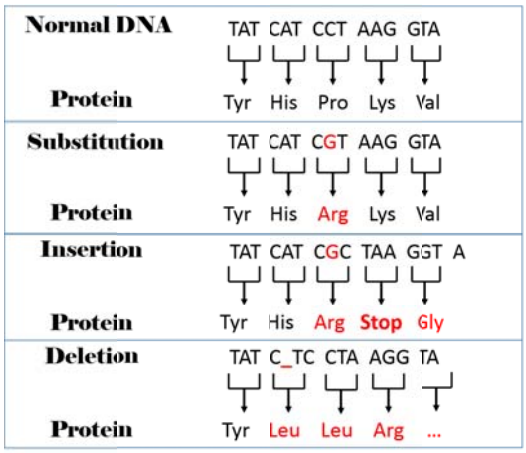


Figure 1

Image file: Figure1.png

ADA Description: 4 boxes are shown. The first contains a normal DNA sequence and the resultant protein. The second contains a DNA sequence with one base substituted for another and the new resultant protein. The third box contains a DNA sequence with a base inserted and the new resultant protein. The fourth box contains a DNA sequence with a base deleted and the new resultant protein.

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

Caption: Figure 1. Small-scale mutations. Substitutions are point mutations and change only one amino acid in the protein. Insertions and deletions are frameshift mutations and change every amino acid coded for after the mutation.

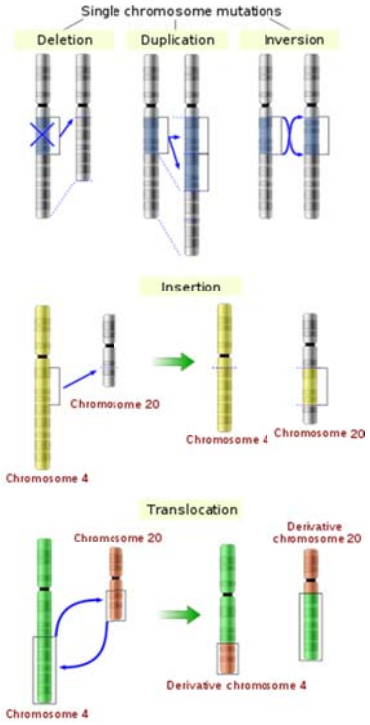


Figure 2

Image file: Figure2.png

ADA Description: Five chromosome mutations are shown. The first shows a chromosome with a portion removed. The second shows a chromosome with a portion duplicated. The third shows a chromosome with a portion inverted. The fourth shows two chromosomes with a portion of one removed and inserted in the other. The fifth shows two chromosomes with a portion of both removed and switched with the other.

Source/Rights: Copyright © YassineMrabet ,Wikimedia Commons (http://commons.wikimedia.org/wiki/File:Chromosomes_mutations-en.svg)

Caption: Figure 2. Large-scale mutations effect entire sections of a chromosome.

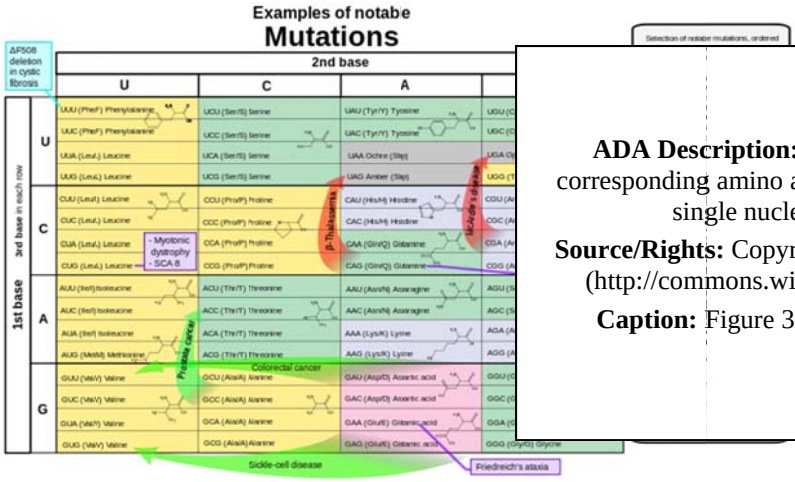


Figure 3

Image file: Figure3.png

ADA Description: A table is shown that converts DNA/RNA to corresponding amino acids. Several arrows show common mutations to single nucleotides can lead to different conditions

Source/Rights: Copyright © Mikael Häggström, Wikimedia Commons (http://commons.wikimedia.org/wiki/File:Notable_mutations.svg)

Caption: Figure 3. Table of small-scale mutations and resultant conditions.

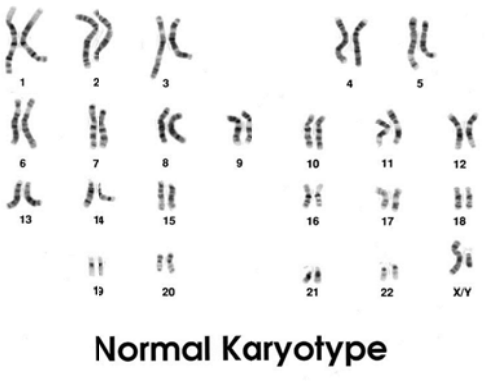


Figure 4

Image file: Figure4.jpg

ADA Description: 46 chromosomes are shown organized into 23 homologous pairs and numbered.

Source/Rights: Copyright © Fae, Wikimedia Commons (http://commons.wikimedia.org/wiki/File:Karyotype_(normal).jpg)

Caption: Figure 4. Normal human male karyotype. Male contains XY as the 23rd pair of chromosomes.

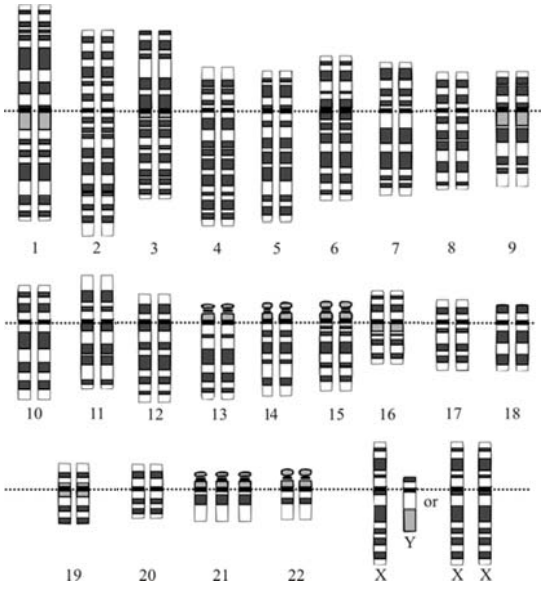


Figure 5

Image file: Figure5.png

ADA Description: 47 chromosomes are shown organized into homologous pairs and numbered. The extra chromosome is in location 21.

Source/Rights: Copyright © Klutzy, Wikimedia Commons (http://commons.wikimedia.org/wiki/File:Down_Syndrome_Karyotype.png)

Caption: Figure 5. Karyotype illustrating trisomy 21. This mutation leads to Down Syndrome

Vocabulary / Definitions

Word	Definition
Chromosome	A long strand of DNA wrapped around a protein, stores instructions to

	create several proteins. Humans have 46 chromosomes (or 23 pairs of homologous chromosomes)
Disjunction	Normal separation of chromosomes during meiosis
DNA	Deoxyribonucleic acid, molecule which contains an organisms complete genetic information
DNA replication	The process by which DNA is copied and passed on to new cells
Gametes	Sex cells, in mammals sperm and eggs, have half the chromosomes of the parent organism
Gene	Subset of DNA/Genome/Chromosome that provides instructions for a cell to build a single protein
Genome	The complete genetic information for an organism, includes all of the chromosomes
Karyotype	A picture of an organisms genome with the chromosomes organized by homologous pairs
Meiosis	Cell division which occurs in sexually reproduction organisms, the result is typically four cells with half the number of chromosomes of the parent. In humans, meiosis results in the creation of sperm or eggs with 23 chromosomes
Mitosis	Cell division which occurs in all organisms, the result is two identical cells with the same number of chromosomes as the parent.
Monosomy	A homolog is missing from a chromosome pair, i.e. if there is only one homolog for chromosome 21, this is called monomsomy 21
Mutagen	Any physical or chemical agent that effects genetic material
Mutation	A spontaneous accidental change in: (1) the DNA nucleotide sequence during DNA replication or (2) a chromosome during meiosis or mitosis
Nondisjunction	Abnormal separation of chromosomes during meiosis
Protein Synthesis	The process by which the instructions contained in DNA are used to produce proteins for a cell or organism
Trisomy	If an extra chromosome is present, i.e. if there are three homologs for chromosome 21 this is called trisomy 21

Associated Activities

Mutation Telephone

Lesson Closure

Assessment

Pre-Lesson Assessment

Pre-lesson Mutation Questions: At the beginning of class have the students answer the short questions on the attached pre-lesson worksheet.

Lesson Summary Assessment

Post-lesson Mutation Questions: After the lesson have the students answer the questions on the attached post-lesson worksheet.

Note: To save paper and ink, since color is important for these worksheets, you may choose to simply display the worksheets on a projector and have the students use their own paper.

Homework

Research: Have the students chose a syndrome caused by a mutation and write a brief 3-5 sentence paragraph on it. Make sure they mention the specific mutation to the chromosome that leads to the syndrome and what effects that mutation will cause.

Lesson Extension Activities

Additional Multimedia Support

References

Attachments

Pre-lesson Worksheet

Pre-lesson Worksheet – Answer Key

Post-lesson Worksheet

Post-lesson Worksheet – Answer 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 performed Fall 2014 at Clear Creek High School, League City, TX for 9th grade regular biology classes. Students were able to learn about different types of mutations and how they occur. This subject is only covered for one class period at the school, so the class could not go into all of the detail provided here but touched on all of the topics. The students really enjoyed the associated activity.

Pre-Assessment Mutations

The questions below pertain to the tiger shown below.

http://commons.wikimedia.org/wiki/File:Panthera_tigris_sumatran_subspecies.jpg

1. **What determines the color of the tiger's coat?**

2. **If the DNA sequence were to change, what would this be called?**

3. **Explain how a mutation could cause this tiger to have a white coat instead of an orange coat.**

Pre-Assessment Mutations

The questions below pertain to the tiger shown below.

http://commons.wikimedia.org/wiki/File:Panthera_tigris_sumatran_subspecies.jpg

1. **What determines the color of the tiger's coat?**

Genes, DNA

2. **If the DNA sequence were to change, what would this be called?**

Mutation

3. **Explain how a mutation could cause this tiger to have a white coat instead of an orange coat.**

A mutation to the gene that codes for the coat color to be orange could cause the coat to change to white

Post-Assessment Mutations

The tiger below is coated different than the one seen at the beginning of class. This coat color was due to a mutation.

http://commons.wikimedia.org/wiki/File:White_Tiger_6_(3865790598).jpg

1. **Explain what a mutation is.**

2. **Explain how this mutation caused this tiger to have a white coat instead of an orange coat.**

3. **Which of these would *most* likely cause this mutation?**

   A the placement of ribosomes on the endoplasmic reticulum
   B the insertion of a nucleotide into DNA
   C the movement of transfer RNA out of the nucleus
   D the release of messenger RNA from DNA

4. **If the DNA sequence for the orange tiger is shown below and the mutated DNA sequence of the white tiger is also shown below. What would the mRNA Codons be for the mutated tiger? _____**

Post-Assessment Mutations

The tiger below is coated different than the one seen at the beginning of class. This coat color was due to a mutation.

http://commons.wikimedia.org/wiki/File:White_Tiger_6_(3865790598).jpg

1. **Explain what a mutation is.**

A random change in the DNA of an organism

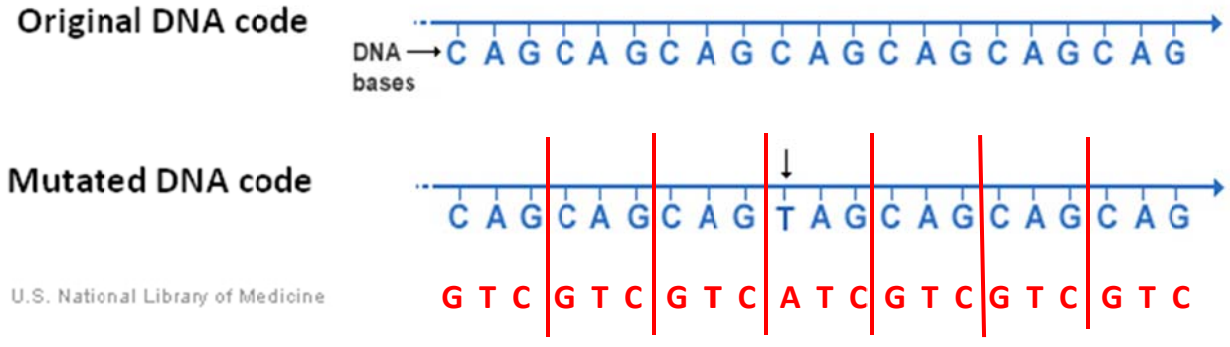
2. **Explain how this mutation caused this tiger to have a white coat instead of an orange coat.**

A mutation to the gene encoding for coat color caused the color to be white instead of orange

3. **Which of these would *most* likely cause this mutation?**

A the placement of ribosomes on the endoplasmic reticulum
B the insertion of a nucleotide into DNA
C the movement of transfer RNA out of the nucleus
D the release of messenger RNA from DNA

4. **If the DNA sequence for the orange tiger is shown below and the mutated DNA sequence of the white tiger is also shown below. What would the mRNA Codons be for the mutated tiger? _____**



Mutated RNA, separated into codons