Microbial Discovery Activity
The RNA Decoder Ring: Deciphering the Language of Life

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Background & Contributors
The RNA Decoder Ring was first presented by Rick Martin and Kirsti Ritalahti as an opening presentation for Teacher-Science Day at the American Society for Microbiology Annual meeting in Chicago on May 30, 1999. It was also demonstrated at a poster session during that meeting. The RNA Wheel templates in this paper were drawn by graphic artist Yunjung Kim of IADS, Hongik University, Seoul, South Korea.

Intended Audience

K-4   X
5-8   X
9-12  X

Activity Characteristics

Class room setting           x
Requires special equipment   
Uses hands-on manipulatives  x
Requires mathematical skills 
Can be performed individually x
Requires group work
Requires more than (45 min) class period
Appropriate for special needs student
Introduction

Description
Here we describe the construction of an RNA Decoder Ring and provide activities for its use that illustrate the language-like nature of the genetic code of life.

Abstract
The DNA molecule is often and aptly compared to a written language that uses only 4 letters; A, C, G and T. The linear sequence of these letters provides information that guides the synthesis of RNA and proteins and through these products defines the characteristics and abilities of individual organisms. To assist students to understand how a 4-letter alphabet can carry coded information and how that information gets translated, we have developed a tool that students can assemble, and activities they can use to decipher the genetic code in fun and familiar ways. The tool is the RNA Decoder Ring that allows students to align the 64 codons specified by the 4-letter genetic alphabet to determine which amino acid each codon encodes. When single letter amino acid abbreviations are used, DNA sequences can be constructed that translate into amino acid sequences that spell out familiar words and phrases in English. We present activities that challenge students to decode messages written in DNA that spell out English words and phrases in their corresponding amino acid sequence. Students are also instructed how to design their own coded messages using the Decoder Ring in reverse. We also provide activities that illustrate the impact that various mutations in the DNA sequence can have on their protein products. Finally we provide an activity that illustrates how the coded language of DNA is used in cells going from DNA to RNA to the amino acid sequence using the initial portion of the human growth hormone gene.

Core Themes Addressed

<table>
<thead>
<tr>
<th>General Microscopy Concepts</th>
<th>Microbial Cell Biology</th>
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</thead>
<tbody>
<tr>
<td>Microbial Genetics</td>
<td>X</td>
</tr>
<tr>
<td>Microorganisms and Humans</td>
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<td>Microorganisms and the Environment</td>
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<td>Microbial Evolution and Diversity</td>
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<tr>
<td>Other -Common properties of life; Cellular components</td>
<td></td>
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</tbody>
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Keywords
DNA, nucleotide, transcription, translation, codon, amino acids, mutation, ribosome

Learning Objectives

At completion of this activity, students will:
- Understand the meaning of a codon and a gene.
- Understand the 3 to 1 correspondence between nucleotides and amino acids.
• Appreciate that there are redundancies in the genetic code and that more than one codon can code for the same amino acid.
• Be able to transcribe a DNA sequence into RNA, and translate an RNA sequence into an amino acid sequence.
• Understand how changes in a DNA sequence (mutation) may or may not alter the corresponding amino acid sequence.
• Appreciate that changes in amino acid sequences alter the properties of proteins.

National Science Education Standards Addressed

The activities described here will assist in achieving science education standards targeted at “Science as Inquiry” and “Life Sciences”. Students will gain practice in the “use of appropriate tools and techniques to gather, analyze and interpret data”, assisting with the science as inquiry standard. Incorporated in the middle school life science standards, teachers can use these activities to help students succeed in understanding “reproduction and heredity”, while in high school standards, these activities illustrate and clarify both the “molecular basis of heredity” and “biological evolution”.
Student Prior Knowledge

The RNA Decoder Ring is designed to provide tactile practice working with the genetic code, and is best utilized after covering the basics of DNA structure and the processes of transcription and translation. The A – T, G – C base-pairing rule for the DNA molecule and the A – U, G – C base pairing rule for transcription of DNA into RNA should also be discussed as students will need to apply these concepts when completing the RNA Decoder Ring activities. Covering the definition of a gene either prior to or during the use of the RNA Decoder Ring will allow students to recognize the presence of start and stop codons, and understand that a gene consists of a discrete length of DNA that contains enough information to direct the correct assembly of a protein. The impact of changes in the DNA sequence (mutations) on the proteins they encode can be introduced in conjunction with the mutation activities in this paper.

Teacher Background Information

DNA carries the genetic information for all cellular life forms on the planet. When passed from parents to offspring, the DNA molecule ensures that the offspring will have the same basic form and abilities of its parent(s). DNA accomplishes this by serving as the record of the information and instructions that directs the production of proteins that in turn provide each cell with its ultimate form and abilities.

The structure of the DNA molecule allows it to carry this information and pass it on to the rest of the cell. The DNA molecule is comprised of two linear strands of subunits called nucleotides. Four different nucleotides are used to build DNA; adenine (A), cytosine (C), guanine (G) and thymine (T). The order that these nucleotides occur within the DNA molecule is very important. The order of nucleotides carries information, much like the letters of the alphabet arranged in a specific order, carry information in the form of words and sentences.

The two strands of the DNA molecule are organized in a specific fashion; where you find an “A” on one strand you’ll find a “T” on the other, and where you find a “G” on one strand, there will be a “C” on the other. This relationship is consistent throughout all life, and is often referred to as the “A-T, G-C rule”.

The DNA molecule with its 4-letter alphabet carries information for the construction of proteins. Proteins are also linear molecules built of subunits, but in proteins the subunits are amino acids, and they come in 20 varieties. In order for the DNA’s 4-letter alphabet to be used to define how 20 different amino acids should be put together to form a protein, DNA’s letters are read in blocks of 3, so that 3 nucleotides in a row encode 1 amino acid of a protein. A block of 3 DNA letters is called a
**codon.** If you add up the number of ways a 4-letter alphabet can be arranged in unique 3-letter combinations, you’ll find there are precisely 64 ways, thus there are 64 codons that can be used to direct the assembly of proteins from 20 different amino acids. Since 64 is greater than 20, some of the codons are redundant, in that they encode the same amino acid. A stretch of DNA that contains the information for the assembly of one protein is called a **gene.**

Proteins are assembled by cellular structures called **ribosomes.** However, the DNA instructions for correctly assembling proteins are safely packaged in chromosomes and cannot be read by the ribosome directly. To provide the DNA’s instructions to the ribosome, a gene’s worth of DNA is first copied into a single-stranded **RNA** molecule. RNA is very much like DNA in that it is made of a linear chain of 4 different nucleotides. RNA has A’s, C’s and G’s like DNA does, but does not have T’s. In RNA a very similar nucleotide, **uracil,** is used, which goes by the single letter abbreviation “U” and specifically binds with “A” just as “T” does in DNA. The process of copying a gene’s worth of DNA into RNA is called **transcription.** The product RNA is called a **transcript,** and it will carry DNA’s instructions to the ribosome and direct the assembly of amino acids into a protein. The process of using RNA instructions to build a protein is called **translation,** an appropriate name as what essentially happens is the translation of a nucleotide sequence language into an amino acid sequence language.

The translation process requires 3 types of RNA molecules. The type that carries the coded information for the assembly of proteins from amino acids is called messenger RNA or **mRNA.** A second type of RNA is a structural component of the ribosome, and is referred to as ribosomal RNA or **rRNA.** The third type of RNA is responsible for carrying amino acids to the ribosome where they can be used to build proteins, and this type is called transfer RNA or **tRNA.** A different tRNA molecule carries each different amino acid, and a tRNA can only deliver an amino acid to the ribosome if that amino acid’s codon is present on the mRNA being read.

With rare exception, the first amino acid used to initiate a protein synthesis is methionine, and the only codon that codes for methionine in mRNA is AUG. Thus “AUG” often is referred to as the **start codon.** When the end of a message is reached, translation stops. The ribosome knows when it has reached the end of a coding sequence because one of 3 possible **stop codons** will be found there. Stop codons do not encode any amino acid, and thus translation stops when a stop codon is reached. The amino acid encoded by the codon immediately preceding the stop codon becomes the final amino acid of the protein.

The following example will help illustrate the flow of information from DNA to proteins:

Nucleotide sequence on DNA:  -CCGGCTCTTCTCTTACTCATACTTATC-

**Transcription**

Nucleotide sequence on mRNA:        -GGCCGAGAAGAGAAUGAGUAUGAAUAG-

**Translation**

Amino acid sequence in protein:            G  R  E  E  N  E  Y  E  S  stop

In the above example, the amino acids are written using their single letter abbreviations (as is done in the activities described later). This example illustrates how information stored in the DNA molecule can be delivered to ribosomes using an mRNA intermediate. This information is then used for the production of proteins, which then determine the unique and defining traits of species.
On occasion, the information content of the DNA molecule can change. This occurs when the nucleotide sequence of the DNA gets altered. Changes in the DNA molecule are called mutations, and can arise from exposure to certain chemicals or types of radiation as well as by mistakes that happen when the DNA molecule is copied in a process called DNA replication. If a mutation arises within the region of a gene which codes for a protein, it may or may not affect the final amino acid sequence of that protein. For example, if a mutation that changes the 3-letter sequence “CCA” into “CCG” in the DNA arises, this would result in the change of the codon “GGU” into “GGC” in the resulting mRNA. GGU and GGC both code for the amino acid glycine, so there would be no change in the final protein as a result of that mutation. Such mutations that don’t alter the protein encoded by a gene are called silent or same-sense mutations.

Other outcomes are possible when mutations arise that do alter the protein product of a gene. A missense mutation occurs when a change in the DNA alters a codon in the mRNA so that a different amino acid is inserted into the protein at that location. For example, if a mutation arises that changes the 3-letter sequence “CCA” into “GCA” in the DNA, this would result in the change of the codon “GGU” into “CGU” in the mRNA. GGU codes for glycine, but CGU codes for arginine, so there would be a one amino acid change in the protein as a result of this mutation. Mutations also occur that alter more than one amino acid. Nonsense mutations occur when a change in the DNA results in the appearance of a stop codon in the mRNA where one did not previously exist. This will terminate translation early, and produce a shorter protein than the one originally encoded. Frameshift mutations occur from changes in DNA that alter the length of a message and also shift the reading frame which determines how codons are organized. For instance, if one or two nucleotides are inserted into or deleted from the DNA, that will change the reading frame of all codons in the mRNA downstream of that change. Frameshift mutations tend to be deleterious as they disrupt the orderly assembly of amino acids into a random assortment that substantially alters the protein that is produced.

Guidance for assembly and use of the RNA Decoder Ring

The following sections of the paper describe how to assemble an RNA Decoder Ring followed by several activities designed to allow students to gain practice deciphering the genetic code. To save time and avoid sharp tool risks, teachers of younger students may want to have the pieces of the Decoder Ring cut out ahead of time, and simply allow the students to assemble them as shown in figure 5. However older students may prefer to build theirs from scratch, allowing more creativity in color selection or materials used. Once constructed, students should be instructed that they need to first convert the DNA sequences provided into mRNA before they can use their Decoder Rings to decipher the coded messages in the activities. There are many ways to expand upon the activities described, particularly by challenging students to come up with their own coded messages or mutations.
METHODS: ASSEMBLY OF THE RNA DECODER RING

Materials Needed for each RNA Decoder Ring:

- 15 x 15 cm piece of foam board, cardboard, or similar support material
- 10 cm diameter circle of foam board or thick cardboard
- Paper templates: RNA wheel, RNA Decoder Ring, 3rd Position arrow and Amino Acid arrow
- Amino acid abbreviation table
- Matt board or thin cardboard paper for RNA Decoder Ring
- Ruler
- Pencil
- Scissors
- Blade for cutting circles out of foam board (a circle cutting tool is very helpful)
- Glue

Directions for Construction of the RNA Decoder Ring:

PREPARATION

1. Print and cut out templates for the RNA wheel (fig. 1), RNA translation ring (fig. 2), the “amino acid” and “3rd position” arrows (fig. 3), and the amino acid abbreviations table (fig. 4).
2. Using a circle cutter or sharp blade, carefully cut out the colored inner circle of the RNA wheel.
3. Measure and cut a 15 by 15 cm square of foam board using a ruler, pencil and a sharp blade.
4. Measure and cut a 10 cm diameter circle from foam board using a circle cutter or a sharp blade.
5. Draw the outline of the RNA translation ring template on the back side of a piece of matt board or a thin cardboard. The outer circle should measure 15 cm, and the inner circle should measure 10 cm. Cut out the ring using a circle cutter or sharp scissors or blade.

PIECING IT TOGETHER

6. Glue the outer circle of the RNA wheel (from step #2) onto the 15 cm square foam board (step #3). Make sure that the edges of the circle are aligned with the edge of the square.
7. Glue the inner circle of the RNA wheel onto the 10 cm circular foam board from step #4.
8. Carefully glue, the elevated inner circle onto the center of the RNA wheel (see figure 5). Alignment must be exact, so do this step with care.
9. Glue the small “3rd Position” and “Amino acid” arrows onto the outer circle opening we cut from instruction #5 and paste the small “3rd position” arrows onto the RNA translation ring from step 5 (see figures 5 and 6).
10. Glue the Amino acid abbreviation table onto the back side of the 15 cm square (see figure 5).
11. Carefully fit in the RNA translation ring over the elevated inner circle of the RNA wheel (figure 5). It should be a snug fit, but loose enough to allow the translation ring to spin easily around the elevated inner circle.
12. If prepared correctly, the 3rd position window should show the 3rd nucleotide of one RNA codon while the amino acid window should show the corresponding amino acid as shown in figure 6.
Figure 1 – RNA Wheel Template. After printing this figure, carefully cut out the colored inner circle. Glue the outer ring to a 15 cm square supporting base, and glue the colored inner circle to a 10 cm diameter elevated disc as illustrated in figure 5.
Figure 2 – RNA Decoder Ring template. After printing, cut out this template and use it to trace a pattern for your Decoder Ring onto a sturdy material such as matt board or thin cardboard. After cutting the ring out of sturdy material, fit it over the elevated inner circle as illustrated in figure 5.
Figure 3 – “3rd Position” and “Amino Acid” arrows. After printing, cut out these arrows and glue them onto the Decoder Ring as illustrated in figure 5.

RNA Decoder Ring

To translate an RNA sequence:
- divide sequence into codons (blocks of 3 letters)
- spin decoder ring into place to spell first codon
- record amino acid encoded
- repeat process until sequence is completely translated

Example:
CUA|AUC|UUC|GAG → L I F E
(RNA sequence) (amino acid sequence)

Amino Acid Abbreviations

| A | Ala | Alanine |
| C | Cys | Cysteine |
| D | Asp | Aspartate |
| E | Glu | Glutamate |
| F | Phe | Phenylalanine |
| G | Gly | Glycine |
| H | His | Histidine |
| I | Ile | Isoleucine |
| K | Lys | Lysine |
| L | Leu | Leucine |
| M | Met | Methionine |
| N | Asn | Asparagine |
| P | Pro | Proline |
| Q | Gln | Glutamine |
| R | Arg | Arginine |
| S | Ser | Serine |
| T | Thr | Threonine |
| V | Val | Valine |
| W | Trp | Tryptophan |
| Y | Tyr | Tyrosine |

Figure 4 – Amino Acid Abbreviations table with brief instructions. After printing, cut out this table and glue it to the back side of the RNA Decoder Ring as illustrated in figure 5.
Figure 5 – Assembly of the RNA Decoder Ring. In this diagram, the inner circle of the RNA wheel template from figure 1 has been cut out and glued to the elevated inner circle (part 2). The remaining outer ring from figure 1 has been glued to the 15 cm square supporting base (part 1). To assemble the Decoder Ring, glue the elevated inner ring (part 2) to the center of the supporting base (part 1). Glue the “3rd Position” arrow (part 4a) and “Amino Acid” arrow (part 4b) to the Decoder Ring (part 3) as shown. Then place the ring over the elevated inner circle. Finally, glue the amino acid abbreviation table (part 5) to the back of the RNA Decoder Ring to allow for easy reference on the use of the Decoder Ring and to the amino acid names.
Figure 6 – Assembled RNA Decoder Ring. In this photo, the ring is set at RNA codon “AUG” which codes for amino acid “M” or methionine. When assembled, the Decoder Ring should spin smoothly around the elevated inner circle to reveal all 64 codons and their corresponding amino acids.

Safety

The activity is devised to allow students to create the RNA Decoder Rings safely with limited assistance. Teachers should be aware of the dangers of sharp tools when handing them out to students and provide assistance when needed. Students in middle school may benefit from having the DNA Decoder Ring parts cut out in advance which would avoid the risk of handling sharp tools. Supervision from teachers or other adults should be provided if students are allowed to use sharp tools.
Assessment

The learning objectives can be assessed using activities 1 – 4 of the Student Handout. All activities require that students first transcribe a DNA sequence into RNA, and translate that RNA into the amino acid sequence of a protein. If a student successfully completes these activities it will demonstrate that he or she can transcribe DNA into RNA, translate RNA into protein, and understand the 3 to 1 correspondence between nucleotides and amino acids. Successful completion of activity 1 will demonstrate understanding of the redundancies found in the genetic code. Successful completion of activities 3 and 4 will demonstrate learning of the consequences of mutation in DNA on the structure of proteins.

Additional Resources

A very nice collection of text descriptions, images and videos describing the DNA molecule and its role in cell functions and inheritance can be found at the “DNA from the Beginning” web page at http://www.dnafb.org/dnafb/

Another useful collection of information complete with teaching aids regarding the DNA molecule can be found at the “DNA Interactive” website, http://www.dnai.org/index.htm
Introduction

DNA is the storehouse of genetic information for life on Earth. This information is vital for the wellbeing and normal functioning of cells. Stored within the nucleotide sequence of a DNA molecule are the instructions for building proteins. It is proteins that allow life to exist through their role as enzymes, as structural components of cells, as channels for transport, as cellular communicators, as motility organs, and by way of numerous other vital roles. Ultimately, living things are what their proteins allow them to be, and the proteins they can make are determined by the DNA they inherit. In the following activities you will see how DNA carries information for building proteins, and how this information is utilized by cells through the processes of transcription and translation.

How to Use Your RNA Decoder Ring

After you have finished constructing your RNA Decoder Ring, you will use it to complete several exercises in the activities provided in your student handout. The example below will assist you in understanding how to use your Decoder Ring.

First, you must transcribe the DNA sequence provided into mRNA:

DNA: GATTAGAAGCTCACT

mRNA: CUAAUCUUCGAGUGA

Next you should group the nucleotides into sets of three; these are your mRNA codons:

mRNA: CUA | AUC | UUC | GAG | UGA

Finally, use your Decoder Ring to translate the codons into amino acid sequence. To translate the mRNA above, first find “C” quadrant in the inner circle (it is in the lower left). Next, find the letter U in the second circle of the “C” quadrant; it is pointing at eight o’clock. Finally, spin your ring around until the 3rd position window shows the letter “A” within the “U” portion of the “C” quadrant. Once the 3rd position displays the letter “A” look in the amino acid window. The amino acid abbreviation will be “L” for leucine.

Continue these steps with the remaining codons. When done correctly, the DNA sequence you transcribed will translate into the amino acid sequence spelling “L-I-F-E”. You will notice that the last codon “UGA” corresponds with a “STOP” which does not designate an amino acid. Instead, it is a “stop” signal, marking the end of the coding region of the mRNA and the completion of the protein encoded by it.
Now that you have learned how to use your RNA Decoder Ring, simply follow these steps when completing the exercises in the activities that follow.

**Activity 1a: Decipher the Coded Message**

In this activity you are given the sequence of a single strand of a DNA molecule. You must first transcribe the DNA sequence shown (template strand) into mRNA, and then use your RNA Decoder Ring to translate the mRNA sequence into amino acids. Use the single letter abbreviations to represent the amino acid sequence. Finally fill in the sequence of the second (complementary) DNA strand shown.

DNA: TAAACGCCTGCTCCATGATAGCCGAGCTCTCTTTATGAAGGCTGTTACGGATT

mRNA:

Protein:

**Activity 1b: Create Your Own Coded Message**

In this activity you will write your own message in DNA code. First come up with a message at least 10 amino acids long using the single letter amino acid abbreviations. You cannot use the letters O, U, B, J, X or Z as they do not have a corresponding amino acid. After you have a message in mind, use your RNA Decoder Ring to determine an RNA sequence that would code for that string of amino acids. To do this, line up the first amino acid in amino acid window of the decoder, then write down the codon that codes for it in the mRNA space below. Repeat this for the remaining amino acids of your message. Lastly convert the RNA sequence into its corresponding DNA code.

DNA: DNA:

mRNA:

Protein:

**Thought Question:** How many different mRNA sequences are possible for your protein? To answer, multiply the number of different codons for each amino acid. For example in the protein “M-A-N”, there is one codon for “M”, 4 codons for “A” and 2 codons for “N” so the total number of different mRNA’s would be 1 x 4 x 2 = 8 different mRNA’s.
Activity 2 – DNA Crossword Puzzle

In this activity, you are provided clues written in DNA code that will allow you to solve the crossword puzzle. You must first transcribe the DNA sequence for each clue into mRNA, and then divide the mRNA sequence into codons. Finally, use your RNA Decoder Ring to find the amino acid corresponding to each codon, and write the single letter abbreviations of the amino acids into the squares provided for each clue. The amino acid sequences will spell out words associated with DNA, RNA and proteins.

ACROSS
3. TGGTCCTTGC
6. TCCCTTTTGCC
7. TCCCCGACTATATAATTGCCAAATCTCCTCGGTACCTC
8. TGGGCCCGCTTAAGAACAGCCTAAGGGTGG
10. GGGATATCCTAATACTATCTGTAGTTGCTTAGG
11. CCCCTTTTACTC
12. AAAGCCCTCCTACTTGCCCTAAACGTTTTCCCCTCAAAAGATATTGGGTG
14. TGCGTGATATACTAATTGCTT

DOWN
1. TACTAAAGAAGGCTTTTATCGCTT
2. TACTCCCTTGCC
4. AAAGCCCGGTACCCTTATGTTGCTAATATGG
5. AAAGCTCGGTTAACGTATAGGACGGCCTAAACATTT
9. CGGCTGCTCTGTAAAAATGGTTGCTTAGG
13. CTGGTGATATACTAATTGCTT
Activity 3 – The Impact of Mutation

The sequence of nucleotides in the DNA molecule is very important as it carries the information for the correct assembly of proteins, and this information needs to be correct and reliably maintained and replicated. However, over the course of a lifetime, a cell’s DNA can change due to exposure to radiation, certain chemicals, viruses, or due to mistakes that arise when the DNA molecule is copied. These changes are called mutations, and they can have modest to substantial effects on the cell. In this activity, you will investigate what can happen to a message when the original DNA code is mutated. Start by transcribing and translating the original DNA code below to determine the amino acid sequence of the original gene. Then compare the mutated DNA sequences that follow to see how these mutations affect the end product.

Original DNA:

DNA: TGAGTGAAGAGCTAGAGTTACATGAACTAAAAGCTCACT

mRNA:

Protein:

Mutation #1: Synonymous (same-sense, silent) mutation

Compare the DNA sequence below to the original one above and circle the single nucleotide change that has occurred. Then write the new mRNA and protein sequences that result from this change. What effect did this mutation have on the protein product?

DNA: TGAGTGAAGAGATAGAGTTACATGAACTAAAAGCTCACT

mRNA:

Protein:

Mutation #2: Missense mutation

Compare the DNA sequence below to the original one above and circle the single nucleotide change that has occurred. Then write the new mRNA and protein sequences that result from this change. What effect did this mutation have on the protein product?

DNA: TGAGTGAAGAGCTAGAGTTACATGACCTAAAAGCTCACT

mRNA:

Protein:
Mutation #3: Nonsense mutation

Compare the DNA sequence below to the original one and circle the single nucleotide change that has occurred. Then write the new mRNA and protein sequences that result from this change. What effect did this mutation have on the protein product?

DNA: TGAGTGTAAAGCTAGAGTTACATTAACTAAAAGCTCACT

mRNA: 

Protein: 

Mutation #4: Frameshift mutation

Compare the DNA sequence below to the original one and circle the single nucleotide change that has occurred. Then write the new mRNA and protein sequences that result from this change. What effect did this mutation have on the protein product?

DNA: TGAGTGTAAAGCTAGATACATGAACTAAAAGCTCACT

mRNA: 

Protein:
Activity 4 – The Growth Hormone Gene

Growth hormone is a protein produced by the pituitary gland that stimulates the elongation of bones and the growth of muscle tissue during childhood and adolescence. A mutation in the gene for growth hormone could result in an altered growth hormone protein, which could then result in stunted growth. Below is a 102 nucleotide stretch of DNA that contains the beginning part of the growth hormone gene. In this activity, you will first transcribe the DNA shown into mRNA. Then scan the mRNA for the first AUG codon. This is the first codon of the message, and starting here will ensure that the mRNA is read in the correct reading frame. Continue translating the mRNA using your RNA Decoder Ring until you reach the end of the piece of mRNA shown.

<table>
<thead>
<tr>
<th>DNA:</th>
<th>mRNA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTGGATCGACGTTACCGATGTCGGGCTGCAGGGACGAGGACCGAAAA</td>
<td>CCGGACGAGACGGGACCAGAAGTTCTCACGGAAGGGTTTGTAAC</td>
</tr>
</tbody>
</table>

Protein:

Questions:

1. The entire growth hormone protein has 217 amino acids. How many nucleotides would be found in the region of the mRNA coding for this protein? (Include the stop codon, but not leading or trailing regions of the mRNA).

2. How might the function of growth hormone be affected if the growth hormone gene picked up the following mutations:
   a) A nonsense mutation altering codon 109:
   b) A same sense mutation affecting codon 21:
   c) A frameshift mutation beginning at codon 155:

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1The growth hormone gene and protein sequences were recovered from the GeneBank database hosted by the National Commission on Biotechnological Information (NCBI), reference number NM_000515.3.
Appendix 1: Solutions to Activities

Activity 1a – Decipher the Genetic Code

Protein = I Carry My Parents DNA

Activity 2 - Crossword Puzzle Solution:

```
M
TRNA
Miss
TRNA
Reading Frame
A
Transcript
S
A
C
E
S
P
R
I
M
D
E
S
A
D
E
S
C
E
A
S
A
N
A
C
K
```

Activity 3 – Impact of Mutations

Original Protein = This Is My Life

Mutation #1: TGAGTGAAAGATAGAGTTACATGAACCTAAAAGCTCACT

New Protein: = This Is My Life

Mutation #2: TGAGTGAAAGCTAGAGTTACATGACTAAAAGCTCACT

New Protein: = This Is My Wife

Mutation #3: TGAGTGAAAGCTAGAGTTACATTAACCTAAAAGCTCACT

New Protein: = This Is M (stop)

Mutation #4: TGAGTGAAAGCTAGAGTTACATGAACCTAAAAGCTCACT

New Protein: = This Is y v l d f r v
Activity 4 – Growth Hormone Gene

Growth Hormone Protein (first 30 amino acids) = MATGSRTSLLLAFGLLCLPWLQEGSAFPTI
Appendix 2: Additional color templates for the RNA Decoder Ring

The orange template below is recommended for black and white printing.