Genes

DNA Replication

Classwork

1. Explain why it is necessary to be able to replicate DNA in order to sustain life.
2. What is the appropriate scientific term used to describe 'a series of bases that code for a protein'?
3. If a strand of DNA is found to contain 250 adenine bases, how many thymine bases does it have?
4. Suppose you are analyzing a strand of DNA that contains 400 cytosines. If the strand contains a total of 1,000 bases, how many adenines does it contain? Why do you know this to be true?
5. Why are the two strands of a molecule of DNA referred to as 'complementary'?
6. What is a ‘template’ strand in terms of DNA replication?
7. What is the physical difference between a 5’ end and 3’ end of a DNA molecule?
8. DNA strands are considered to be antiparallel. How would the molecule appear differently if they were ‘parallel’ instead?
9. Why are new DNA strands only created in a 5’→3’ direction?
10. A landmark study in DNA replication research by Meselson and Stahl involved growing bacteria including an isotope of nitrogen $^{15}$N and then placing these bacteria in a medium containing only $^{14}$N. According to the known method of DNA replication, what do you predict the ratio of the two isotopes would be in DNA from the first round of reproduction?
11. In what way is DNA polymerase similar to a waiter or waitress in a restaurant?
12. DNA polymerase (specifically Taq polymerase) has to be added to the mixture when DNA is placed in a PCR machine. Explain the importance of adding the polymerase.
13. A forensic technician has placed a single strand of DNA into a PCR machine, along with appropriate polymerases and primers. How many DNA molecules will be present after 20 cycles?
14. Suppose you are a doctor studying a disease that destroys DNA polymerase enzymes in the cell. What impact do you predict this will have on the reproductive ability of the affected cells?

Homework

15. Why do we often describe a DNA molecule as an ‘archive’ of information?
16. Can you accurately predict the number of cytosine bases found in a DNA strand if provided with only the number of thymine bases in that strand?
17. Match the single strand of DNA below with its complementary strand:
   TACGGCATC
18. Suppose you are analyzing a strand of DNA that contains 375 thymines. If the strand has 900 bases, how many guanines does it have?
19. In a newly replicated molecule of DNA, how much of the molecule has just been synthesized, and how much was pre-existing?
20. What end of the DNA strand has a phosphate group attached? The 5', or the 3'?
21. The area of a DNA molecule where the replication process takes place is often referred to as a ‘replication fork.’ Explain why you think this term is used to describe this location.
22. Explain what the term ‘antiparallel’ means in terms of DNA replication.
23. Does DNA polymerase use the template strand or the daughter strand to complete the replication process? Explain.
24. A forensic technician has placed a single strand of DNA into a PCR machine, along with appropriate polymerases and primers. How many DNA molecules will be present after 50 cycles?
25. Temperature is very important in the PCR process. Explain.

Transcription
Classwork
26. How does the sequence of nitrogenous bases affect the appearance of a molecule of RNA?
27. Why is the process of transcription essential to the utilization of DNA?
28. What role does the promoter region of a DNA sequence play in the transcription process?
29. Does RNA polymerase bind to the template strand or non-template strand of DNA? Explain why this makes sense for creating RNA that contains the needed information contained in the DNA molecule.
30. Match the strand of DNA below with its appropriate mRNA sequence.
   TACGGTCATTGA
31. Considering the 5' and 3' ends, in which direction is a molecule of RNA synthesized?
32. Why are both the non-template DNA strand and mRNA both 5'→3' in orientation?
33. Which nitrogen base is involved in transcription but not DNA replication? Why is this the case?

Homework
34. How does the sequence of bases impact the physical structure of RNA differently than DNA?
35. What enzyme conducts the process of transcription in cells?
36. What does the ‘m’ in mRNA represent? Why did scientists designate it with this name?
37. Match the strand of DNA below with its appropriate mRNA sequence.
   TACTGGTTCAGC
38. Compare the promoter and termination sequences of DNA to a traffic light.
39. Does the process of DNA replication involve uracil? Why or why not?
40. How does a strand of mRNA compare to the non-template strand of DNA from which it was created?

**Gene Expression Overview**

**Classwork**

41. How many nitrogen bases compose a single codon?
42. What is the relationship between codons and proteins?
43. Create a flow chart using words and arrows to show the entire process of gene expression. (You should use 5 words)
44. What three letters will begin all mRNA sequences that code for proteins? Explain your answer.
45. What is the ‘central dogma’ of biology? Explain why this saying is used to describe the biological concept.
46. If you were to sequence the DNA of a housefly, what bases would you find in its genome?
47. Why are DNA, RNA and their codons referred to as the *universal* code of life?
48. What does the comprehensive gene expression process throughout living organisms suggest about the origins of life?
49. Sometimes the term ‘protein synthesis’ is used to describe gene expression. Explain the relevance of this term to this process.
50. The fact that a single amino acid may be coded for by multiple codons may help to diminish the negative effects of a DNA mutation. Explain why this may be true.
51. How are the *termination* steps of transcription and translation different?
52. What amino acid is specified by the codon AUG?
53. What amino acid is specified by the codon UCG?

**Homework**

54. In what way are codons similar to airport codes? (ex. PHL = Philadelphia)
55. What amino acid will you find in the beginning of all sequences that create proteins?
56. What DNA and RNA bases would you find in the DNA of a blue whale?
57. How many codons, when expressed, will stop the translation process?
58. Explain why the term ‘gene expression’ is utilized when describing the process of generating protein from DNA.
59. How could a change in the DNA sequence of a gene have an impact on the translation process?
60. Suppose an error occurs in the translation phase of gene expression. Will this error affect the DNA sequence of the gene? Why or why not?
61. In which step (initiation, elongation, termination) are new amino acids added during translation?
62. How are the codons that specify a protein similar to the words that make up a sentence? What would happen if you were to change the sequence of the words?
63. What amino acid is specified by the codon UCA?
64. What occurs in the translation process when the codon UGA is reached?

**Translation**

**Classwork**

65. Why is the term ‘translation’ appropriate for the last step of gene expression?
66. What is the role of rRNA in the process of protein synthesis?
67. What does the ‘t’ in tRNA represent? Why is this an appropriate name when considering the role of this molecule in the translation process?
68. What part of a tRNA molecule specifies the amino acid to which it will bind?
69. How does the codon sequence of mRNA specify which tRNA molecules will bind to the mRNA?
70. If an mRNA codon reads UGC, what is the anticodon on the tRNA molecule with which it will bind? What amino acid will this tRNA molecule carry?
71. What is the anticodon on the first tRNA molecule that will begin every translation process? How can you predict this accurately?
72. In what way is a tRNA molecule that has taken part in translation different before and after the process?
73. Why is it important for the efficient production of proteins that the cell has many tRNA molecules available?
74. What is the role of the ‘P’ site in translation?
75. What will occur in the ribosome when the codon UAG is reached on the mRNA?
76. Describe the relationship between genes and proteins.
77. Below is a template strand of a gene that codes for a protein. Provide the related mRNA, tRNA and amino acid sequences.
   
   TACGGTCTACCGACT

78. Define the term mutation and give an example of a substitution mutation and an example of a frameshift mutation in a DNA strand.
79. What is the final product of a strand of DNA that has undergone a mutation?

**Homework**

80. Where does the process of translation occur in the cell?
81. What is the role of tRNA in the process of translation?
82. If an mRNA codon reads CCU, what will its complementary anticodon be? Which amino acid will the tRNA carry?
83. If there are only 20 amino acids used in the process of translation, explain the existence of thousands of different types of proteins in living organisms.
84. What is the relationship between codons and anticodons in the translation process?
85. In what way is the ‘A’ site on the ribosome similar to a loading dock at a warehouse?
86. How does the ribosome link individual amino acids together during the process of translation?
87. Compare the process of translation to the process of writing a sentence. What does each letter represent? What does the completed sentence represent? What would happen if the words or letters were in the incorrect order?
88. Explain how the termination segment of translation occurs.
89. What is the final product of the translation process?
90. How is ‘translation’ in terms of biology similar to ‘translation’ in terms of linguistics?
91. Below is a template strand of a gene that codes for a protein. Provide the related mRNA, tRNA and amino acid sequences.
   TACCGCTTAGTCATT
92. Discuss how a mutation in DNA can affect the function of a resultant protein.
93. Discuss how a mutation affects the processes associated to the Central Dogma.

**Free Response**

1. The production of mRNA is a critical step in transmitting the information from DNA out into the cell where the information will be utilized. Respond to the prompts below based upon the production of mRNA within the nucleus.
   a. What is the name of the process of producing mRNA?
   b. List and describe the steps within this process. Include where the process begins on the DNA strand, which DNA strand is used, the name of and type of molecule that produces the mRNA and how this molecule “reads” the DNA strand.

2. Below is an illustration of translation. Use this illustration to respond to the prompts below:
   a. Identify the items labeled 1, 2 and 3 in the illustration
   b. Describe the role of item 1 in the process of translation
   c. Describe the role of item #2 in the process of translation.
3. The amino acid sequence of a protein is critical to its primary shape. Its primary shape is critical for the proper functioning of the protein. How does the process of translation ensure the correct sequence of amino acids?

4. A complete set of human genetic material contains approximately $3164.7 \times 10^6$ base pairs. It is estimated that 99.9% of the bases are exactly the same in all people. If this is correct, how many base pairs are the same in all people?

**Genes Answer Key**

1. If a cell is to reproduce, it must replicate its DNA as well. Each cell needs a complete copy of DNA in order to function properly.
2. Gene
3. 250
4. 100. If the strand contains 400 cytosines, it also contains 400 guanines. This leaves 200 bases composed of adenines and thymines, there would be 100 of each in the strand.
5. Each strand goes with a pair, so a single strand is said to 'complement' another strand. In DNA, one strand ‘goes with’ another.
6. A template strand is the strand that is used to make a new strand of DNA. The new strand will match the bases currently in existence on the template strand, and the two strands, one old, one new, will be complementary.
7. The 5’ end has a phosphate group, the 3’ end has an OH group.
8. The strands would run in the same direction, so the 5’ and 3’ ends would be on the same side, instead of on opposite ends as in antiparallel.
9. Nucleotides can only be added to the 3’ end of the template strand, and since the new strand is antiparallel to the template, the new strand is made from 5’ to 3’.
10. The ratio will be 1:1, or an equal amount of each isotope. Since DNA replication is semi-conservative, each new strand in the reproductive cycle will consist of $^{14}$N, while each template strand will contain $^{15}$N.
11. Just as a waiter or waitress brings a selected item to a diner in a restaurant, DNA polymerase brings a selected nucleotide to the next location in a newly synthesized strand.
12. DNA polymerase must be added because it is the enzyme that catalyzes the addition of nucleotides to the growing DNA strand. Without it, DNA replication could not take place. *Taq* polymerase is specifically used because it has a high optimal temperature.
13. 1048576
14. The affected cells will be unable to reproduce, a cell cannot reproduce without replicating its DNA, and DNA replication cannot occur without DNA polymerase.
15. DNA is very effective at holding, cataloguing a vast amount of information. It cannot, however, utilize or interpret this information without the assistance of other molecules.

16. No. You can accurately predict the number of adenines, but without the total number of bases in the strand, the number of thymines cannot help you determine cytosine numbers.

17. ATGCCGTAG
18. 75 guanines
19. Half of the molecule is new, half is pre-existing.
20. The 5’ end of the DNA strand has the phosphate group attached.
21. The DNA is unwound, to expose the bases so DNA polymerase can add new, complementary bases. Where this unwinding occurs, the separated strands create a ‘Y’ shape, like a fork in the road.
22. Antiparallel means that one strand of a DNA molecules runs from the 5’ end to the 3’ end, while the matching strand runs from 3’ to 5’.
23. The template strand. The DNA polymerase carries the base that is complementary to the bases on the template strand to help create the daughter strand.
24. $1.13 \times 10^{15}$
25. High temperature is necessary to separate the DNA strands. The temperature must then be decreased to allow DNA primers and polymerases to anneal (stick). The temperature is then slightly increased to speed the rate of reaction.
26. The sequence of bases determines the shape of the RNA molecule due to hydrogen bonding between base pairs.
27. Transcription allows the information coded in DNA to be transferred to a molecule of RNA, which can actually be interpreted and used to create proteins. Without this process, DNA is like a book that cannot be read.
28. The promoter region can be recognized by RNA polymerase, and cause the RNA polymerase to bind to the DNA and begin transcription.
29. It binds to the template strand. This makes sense because the non-template strand actually contains the bases that build the gene that can be translated into a protein. By creating an mRNA strand from the template strand, the enzyme is creating the same sequence as the non-template strand, which contains the valuable information.
30. AUGCCAGUAACU
31. RNA is synthesized from 5’ to 3’
32. The non-template DNA strand and the mRNA are identical (except for the thymine/uracil), because they are both complementary to the template strand of DNA.
33. Uracil. Uracil replaces thymine in RNA, but since RNA is not involved in DNA replication, uracil does not appear in this process.
34. The sequence of bases can actually affect the way in which an RNA molecule folds and interacts with itself.
35. RNA polymerase
36. Messenger. The mRNA carries information from the DNA to the ribosome, basically becoming a messenger in the process.
37. AUGACCAAGUCG
38. The promoter region of a DNA sequence is like a green light, signaling the transcription process to begin, whereas the termination sequence is like a red light, stopping the process.
39. No. DNA replication only involves DNA, and so uracil is not involved in this process.
40. The strand of mRNA will be identical to the non-template strand of DNA, with the exception that uracil replaces thymine.
41. 3
42. Codons are used to create proteins. Each codon represents an amino acid, which are the monomers of proteins.
43. DNA \rightarrow \text{Transcription} \rightarrow \text{RNA} \rightarrow \text{Translation} \rightarrow \text{Protein}
44. AUG. AUG is the 'start' codon, it codes for the amino acid methionine, and every translation sequence will begin with this codon.
45. Central dogma means 'major theme' or 'underlying idea.' Scientists use this term to describe gene expression, because gene expression is the underlying theme behind all biological activities. Without this process, life as we know it cannot exist, and so it is the 'fundamental belief' around which the rest of life revolves.
46. Adenine, thymine, cytosine and guanine. All living organisms possess DNA that is basically the same in structure, and contains these 4 bases.
47. All life on Earth uses this form of genetic material to live, grow and reproduce. These molecules exist in the same form and basic function in all living organisms.
48. This suggests that all life shares a common ancestry, as the process and molecules that govern life are the same throughout the trees of life. If life on Earth did not share common ancestry, this central process would likely be different between groups of organisms.
49. Genes are segments of DNA that code for a protein. The process of creating proteins (protein synthesis) is also the process of using the information stored in genes to create a substance or accomplish a task. Gene expression and protein synthesis are essentially the same process.
50. If multiple codons represent a single amino acid, it reduces the chances that a single nucleotide mutation would alter the sequences of amino acids in the translation process. If there were only 20 codons for 20 amino acids, a single nucleotide mutation would carry a 100% chance of altering the amino acid sequence. This is often referred to as the 'wobble hypothesis.'
51. In transcription, a termination sequence of DNA signals the RNA polymerase to cease and detach, whereas in translation, one of three codons does not correspond with an amino acid, and cause the translation process to end.
52. Methionine (Start)
53. Serine
54. Just as three letters represent a city in airport codes, three letters represent an amino acid in a codon.

55. Methionine

56. Adenine, thymine, guanine, cytosine, uracil. These bases are the same regardless of the organism.

57. 3 (UGA, UAA, UAG)

58. A gene is a segment of DNA that codes for a protein. Through the process of protein synthesis, your cells are ‘expressing’ genes in the form of proteins for which they code.

59. In many cases, changing just one nitrogen base in a sequence of DNA will alter the sequence of amino acids in the translation process. In some cases, adding or removing a base may alter every amino acid in the protein after the location of the mutation. In either case, the protein may be drastically altered in structure and function.

60. No. The DNA will not be changed by the translation error. DNA is not directly involved in the translation process.

61. Elongation

62. Each codon represents a different amino acid, and many amino acids, when assembled in the correct order, create a functional protein. Each word in a sentence is like an amino acid, with the entire, completed sentence representing the whole protein. If you change one word in the sentence, the entire thing may not make any sense, or may mean something entirely different, just as changing one amino acid in a protein can alter the entire protein.

63. Valine

64. The translation process stops.

65. The process of translation converts RNA to protein, basically changing one form of cellular language into another.

66. tRNA composes the ribosome, the organelle on which the process of translation occurs.

67. Transfer. The tRNA molecules carry (transfer) amino acids from the cell’s interior to the ribosome and the growing amino acid chain.

68. The anticodon.

69. The codons of mRNA are complementary to the anticodons of tRNA. The tRNA with the anticodon that matches the mRNA will bind and the appropriate amino acid will be deposited. A tRNA molecule without the appropriate anticodon cannot bind to the mRNA.

70. ACG, Cytosine

71. UAC. Each coding segment of mRNA begins with AUG, the start codon. UAC is complementary to AUG.

72. A tRNA that has taken part in translation will lack an amino acid, because it will have already deposited the amino acid at the ribosome.

73. The process of translation occurs extremely quickly, and the tRNA molecules with their corresponding amino acids must be available to keep the process moving productively.
74. The ‘P’ site is the location from which the new protein will emerge on a ribosome.
75. The two subunits of the ribosome will disassemble and translation will terminate.
76. The information stored in genes in DNA form is used to create proteins through the assembly of amino acids in a specific order.
77. AUGCCGAGAUGGCUGA; UACGGUCUACCGACU; Met-Pro-Asp-Gly
78. A mutation is a change in the sequence of DNA bases. Examples will vary.
79. If the mutation is silent the protein will not be affected. All other mutations will cause misfolded proteins.
80. Ribosome
81. tRNA carries the appropriate amino acid to the growing amino acid chain.
82. GGA, Proline
83. There are infinite combinations of amino acids that can be used to create what is essentially an infinite number of proteins. A single protein can consist of thousands of amino acids, and changing just one of these amino acids may create an entirely different protein.
84. Codons are sequences of three bases on mRNA that code for an amino acid, anticodons are sequences of three bases on tRNA that carry a specific amino acid as specified by the mRNA.
85. Just as a loading dock is the location where items are picked up or delivered in a warehouse, the ‘A’ site on a ribosome is the location where amino acids are delivered.
86. The ribosome catalyzes the formation of a covalent bond between the amino acid in the A site with the adjacent amino acid in the P site.
87. Each letter represents an amino acid, the completed sentence is a completed protein. If the words or letters were rearranged, the sentence would mean something totally different, or would not make any sense at all. If the amino acids in a protein were rearranged, the protein would have a totally different function, or no function at all.
88. One of the three stop codons is reached on the mRNA. No amino acids correspond to this codon, so no tRNA molecule binds to the mRNA. The ribosome subunits disassemble and the process ends.
89. A completed protein.
90. In linguistics, one language is converted to a different language, in biology, the language of RNA (or ultimately DNA) is converted to the language of proteins.
91. AUGGCGAAUCAGUAA; UACCGCUUAGUCAUU; Met-Ala-Asn-Gln
92. Changes in the DNA can cause a change in the 3D shape of the protein.
93. Mutations do not affect the Central Dogma.

1. The production of mRNA is a critical step in transmitting the information from DNA out into the cell where the information will be utilized. Respond to the prompts below based upon the production of mRNA within the nucleus.
   a. This process is called transcription.
   b. This process (3 points)
1. begins at a location called the promoter region. (a specific sequence of bases on the DNA that the polymerase recognizes)
2. The template DNA strand is used to make the RNA strand
3. It is the RNA polymerase, an enzyme (would also accept a protein), that “unzips” the DNA and produces the mRNA
4. The RNA polymerase “reads” the sequence of bases on the template DNA strand. The complimentary bases are placed into the mRNA

2. Below is an illustration of translation. Use this illustration to respond to the prompts below:
   a. Item #1 represents mRNA. Item #2 represents tRNA. Item #3 represents a protein.
   b. Item #1, the mRNA (2 points)
      - Brings the code to the ribosome in the form of codons.
      - mRNA was produced from the DNA code found in the nucleus
   c. Item #2, the tRNA (3 points)
      - Contains anti-codon on one end which bonds to the codon from the mRNA
      - Contains a specific amino acid on the other end
      - Amino acid bonds to another amino acid to build a protein
3. The mRNA contains a codon in the sequence of nitrogenous bases. This code is a 3 base code. One section of a tRNA has a 3 base codon called the anti-codon. This is because the codon bases on the mRNA must match the anti-codon on the tRNA; U bonds with A, C bonds with G. Each tRNA carries a very specific amino acid. This ensures that a specific code on the mRNA attaches to a specific anti-codon on the tRNA which carries a specific amino acid to be placed into the protein.

4. 3161.5 x 10^6 base pairs are the same in all people