

## **Big Idea 3: Chapter Questions**

### **Big Idea 3A: Inheritance**

#### **3.A.1a Genetic information is transmitted from one generation to the next through DNA or RNA.**

1. Early in the twentieth century it was clear that chromosomes were made of DNA and proteins. In addition, it was known that nuclei carried genes. Robert Feulgen developed a dye that could bind to DNA. The stain was taken up by the cell in direct proportion to the amount of DNA contained in it. By staining cells, he produced evidence that DNA was the genetic material. Explain how each of the following observations provide such circumstantial evidence:
  - a. Cell nuclei were stained
  - b. Nuclei of different species carried different amounts of stain
  - c. Somatic cells contained twice as much stain as sex cells
2. Bacteria of strain A are deadly to rats. Bacteria of strain B are not deadly to rats. When strain A is heated and lysed and then injected, it no longer kills rats. However, when dead strain A is added to a suspension of live strain B bacteria, incubated, and injected into rats, the rats die. Explain how this occurs.
3. Bacteria of strain A are deadly to rats. Bacteria of strain B are not deadly to rats. When strain A is heated strongly enough to destroy the cell membrane and then injected, it no longer kills rats. However, when a sample of lysed A is added to a suspension of live strain B bacteria, incubated, and injected into rats, the rats die. In a variation of this experiment, living strain A is heated vigorously to boiling point for 5 minutes. Killed strain A and live strain B are incubated together and then injected into rats. The rats remain healthy. What conclusions can you draw from these two experiments?

4. Bacteria of strain A are deadly to rats 100% of the time. Bacteria of strain B are deadly to rats 0% of the time. A sample of heat-killed strain A is added to a suspension of live strain B bacteria. This mixture is incubated and injected into rats. 100% of the rats die. Next, three suspensions of heat killed strain A are treated with different protocols before incubating with B and injecting into the rats. Complete the table below and justify your responses.

Treatment of Strain A after heat-killing	Rat mortality upon injection of strain B after incubation with strain A	Justification
None	100%	
Addition of protease		
Addition of RNAase		
Addition of DNAase		

5. Hershey and Chase performed their groundbreaking work with radioisotopes of phosphorous and sulfur. Why would using nitrogen instead of sulfur have been a bad idea? How would their results have been different?
6. Once researchers had discovered that DNA is the genetic material in prokaryotes, experiments were carried out to support the idea that this is also true in eukaryotes. One such experiment involved taking the DNA from a brown duck and injecting it into a white duck. The investigators claimed that the white duck turned brown. Explain why these results are unlikely. Describe the process that investigators could use that would be more likely to have produced these results.
7. Even though James Watson and Francis Crick are popularly known for the discovery of the structure of DNA, their discovery was based on the work of many others including Edwin Chargaff, Linus Pauling, Rosalind Franklin and Maurice Wilkins. Describe how the contributions of these scientists allowed Watson and Crick to make their discovery.

8. A sample of bacteria is grown in a special nitrogen-15 medium. This nitrogen is incorporated into the genetic material as it replicates, making all of the DNA slightly heavy. Some of these bacteria are then transferred to a regular nitrogen-14 medium and allowed to reproduce for several generations. The mass of the DNA is measured in each generation. The results can be found in the table below. Explain how these results signify that DNA replication is a semiconservative process.

Generation of Bacteria	Mass of DNA by proportion of sample (%)		
	Heavy	Intermediate	Light
1	100	0	0
2	0	100	0
3	0	50	50
4	0	25	75

9. A sample of bacteria is grown in a special nitrogen-15 medium. This nitrogen is incorporated into the genetic material as it replicates, making all of the DNA slightly heavy. Some of these bacteria are then transferred to a regular nitrogen-14 medium and allowed to reproduce for several generations. The mass of the DNA is measured in each generation. If DNA replication is a fully conservative process, what results would you expect? Enter data into the blank table and justify your response.

Generation of Bacteria	Mass of DNA by proportion of sample (%)		
	Heavy	Intermediate	Light
1			
2			
3			

10. Describe each of the types of genetic expression shown below and identify the types of biological entities that would use them.

- A. DNA → RNA → protein
- B. RNA → protein
- C. RNA → DNA → RNA → protein

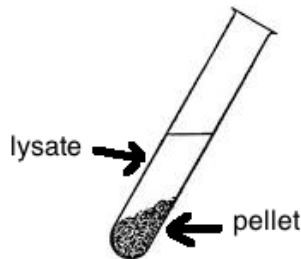
11. Complete the following table:

Property	Nucleic Acid	
	DNA	RNA
Base types		
Base pairing		
Molecular shape		
Location in eukaryotic cells		
Sugar molecule		
Method of production		
Subtypes and functions		

12. Follow the directions below to transcribe and translate a gene sequence.
- a. Make a copy of the following bases in one line in numerical order across the page.

1. T	2. A	3. C	4. C	5. C	6. G	7. C	8. C
9. T	10. A	11. A	12. T	13. C	14. A	15. G	16. T
17. G	18. C	19. T	20. T	21. C	22. C	23. T	24. T
25. T	26. A	27. T	28. C	29. C	30. G	31. C	32. A
33. T	34. G	35. C	36. C	37. C	38. G	39. G	40. A
41. T	42. C	43. G	44. G	45. A	46. A	47. T	48. T

- b. Transcribe the coding strand of DNA into the primary transcript of RNA. Draw this underneath the DNA strand and label it.
- c. Add a poly A tail and an mG cap.
- d. Cut DNA into exons and introns at the appropriate base sequences. Sections containing bases in between GU and AG (including these bases) are introns. Outside of these cut regions are exons. Show cuts on mRNA.
- e. Splice the exons together. Draw this beneath the cut RNA and label it.
- f. Translate the processed RNA into the correct polypeptide using the codon chart. Draw the polypeptide beneath the RNA and label it appropriately.
13. After a bacterial cell is heat killed and lysed, the contents can be placed in a test tube and spun in a centrifuge. This separates the cell materials into a pellet where the heavier cell parts can be found and a lysate where the less dense proteins and DNA can be found. Dr. Avery used this process in order to determine that DNA was the transformative material in bacteria.



- a. **Describe** two ways in which protein and DNA differ structurally and one way in which they differ functionally. Make sure both substances are referenced in each comparison that you make.
- b. If the lysate from a heat killed S type bacteria were added to a culture of R type bacteria, **predict the composition** of the new bacteria culture?
- c. Certain specific enzymes can be added to the lysate that selectively destroy proteins or nucleic acids. **Explain** how Avery used this technique to determine that DNA is responsible for transformation and not protein.

- d. Based on the structural differences you mentioned above in letter “A” **describe what would be observed** if a bacteriophage –after being reproduced in a radioactive sulfur medium – is allowed to infect a colony of a certain bacteria.
14. When detectives investigate a crime scene, they are often presented with a very small amount of DNA, insufficient for extensive analysis. This small sample of DNA must be amplified greatly before it is subject to the large array of tests in a crime lab.
- Describe** the polymerase chain reaction (PCR) and how it is used to amplify DNA.
  - Using your understanding of the three dimensional structure of proteins and DNA, **explain** why DNA can be replicated with relative ease while proteins cannot.
  - Contrast** the denaturation of DNA in the PCR method opposed to how it happens in biological systems prior to replication.
  - Why** are Okasaki fragments not found in PCR but are found in biological replication?

**3A.2 In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis, or meiosis plus fertilization.**

- Draw a sketch of the cell cycle including interphase and mitosis/cytokinesis. Label each subphase of interphase and any checkpoints present. Briefly describe what occurs in the cell at each part of your sketch. Ensure that the sketch correctly represents the proportion of time a typical cell spends in each subphase.
- Consider the following facts:
  - Cyclin proteins are made at only certain times during the cell cycle.
  - Cyclin dependent kinases (Cdk’s) are always present in cells but active only in the presence of cyclins.
  - An inhibitory protein prevents cells from entering the cell cycle at the restriction point R.
  - Active Cdk’s phosphorylate inhibitory proteins and deactivate them.

Based on these facts, which of the following statements is/are probably true? Justify your response to each.

- ATP is required for the regulation of the cell cycle
  - If Cdk’s reach a threshold level, the cell cycle will proceed
  - Cell cycles are allosterically regulated
3. Platelets can have an effect on the cell cycle even though they are external to the cells that divide. Explain how this might occur.

4. Human epidermal growth hormone receptor (HER2) is a protein found on cell membranes and when activated causes an initiation of the cell cycle. In certain breast cancers, there are many more copies of HER2 than normal.
- Explain why more copies of HER2 may lead to breast cancer.
  - Explain what other events must occur in the cell for breast cancer to actually occur.
5. In response to stress, a human cell will initiate the expression of a large number of genes, some of which prevent a cell from moving from the G1 to the S phase. One of these proteins that help stop a cell moving from G1 to S phase is called P21. Another protein, P53, must be present in high concentrations within the cell for P21 to be produced. Over 50% of human cancers can be linked to mutations in the P53 gene sequence.

A. **Describe** the difference between G1 and S phase. Be careful to explain what is happening in each phase.

B. **Explain** why a mutation in the P53 gene may cause a cell to become cancerous.

C. **Describe** the role of cyclins and cyclin dependent kinases (Cdk's) in the cell cycle.

D. P53 can also induce apoptosis. **Explain** what this is and why it would be induced by P53.

### 3.A.3 The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring.

1. Sickle cell anemia is a condition by which the hemoglobin in the red blood cells is malformed. This is caused by a point mutation on chromosome 11 in which a hydrophobic amino acid is coded for instead of the hydrophilic glutamic acid. It is a recessive trait.

A. **Is this** an autosomal disease? **Justify** your answer.

B. **Explain** the difference between the primary and secondary structure of a protein and **explain how** this mutation can affect the proteins secondary structure.

C. **List all** of the possible parent genotypes that could yield a child with sickle-cell disease? Use S for the dominant allele and s for the recessive allele.

D. A male who is a carrier for sickle cell disease has children with a female who is homozygous dominant at this locus.

i) **What is the probability** of a child in the F1 generation being a carrier?

ii) If a carrier from the F1 generation mates with an individual expressing the disorder, **what is the probability** they will have a healthy child?

2. Flower location (axial vs. terminal) in pea plants is dictated by a gene locus present on chromosome 4 in pea plants. The gene locus for plant height (tall vs. short) is also located on chromosome 4 in pea plants and in close proximity to the locus coding for flower location. However, the locus for seed color (yellow or green) is on chromosome 1. The dominant alleles for each trait are axial, tall, and yellow respectively.

- A. **Which traits** (flower location, plant height, and seed color) will sort independently? **Justify your answer.**
- B. When a pea plant with unknown phenotype is crossed with a pea plant that is homozygous recessive for flower location and seed color the following data was collected from the F1 generation.

Table 1: F1 generation collected (200 total offspring)

Axial and Yellow	Axial and Green	Terminal and Yellow	Terminal and Green
97	0	103	0

- i) **What would be the phenotype and genotype** of the unknown pea plant involved in the cross? **Justify your answer** and **provide a key for the letters involved.**
- ii) If an axial yellow plant from the F1 generation were self-pollinated, **what would be the probability** of obtaining plants that have the same phenotype as their parent? **Justify your answer.**

3. Patau syndrome is a disease in humans caused by non-disjunction of chromosome 13. Polydactyly is one of the major symptoms.

- A. **Explain** non-disjunction.
- B. If non-disjunction were to occur in meiosis I for an organism with  $2n=4$ .
- i) **Illustrate how** this occurs clearly showing the progression through meiosis I and II.
- ii) **What is the value of "N"** for each of the gametes produced?

C. **Predict the probability** of producing normal gametes if non-disjunction were to occur in meiosis II. Use an illustration to justify your answer.

D. **Provide two reasons why** a genetic counselor might recommend a 25 year old woman have a child even though her older sister had a child born with Patau syndrome?

### 3.A.4 The inheritance pattern of many genes cannot be explained by Mendelian genetics.

1. In eastern Canada, coyotes are larger than they are out west. Professor Stallone believes that coyote size is determined by Mendelian inheritance patterns. For his



test he studies two populations of coyotes – one that consistently bred to produce large coyotes and one that consistently bred to produce small coyotes. He considered each population homozygous for their respective phenotype. If large was the dominant trait:

- A. **What would be the expected phenotypes and genotypes** in the F1 generation if the coyotes were allowed to breed?  
 B. When Dr.Stallone bred coyotes from the F1 generation, he found the following results:

Sample Size of F2 generation:300 animals

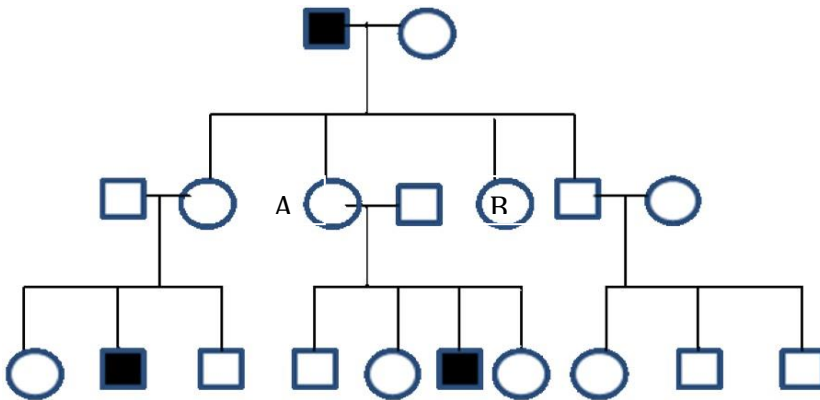
Large = 196 animals

Small = 104 animals

- i) **What would be the expected ratio** of large to small animals in the F2 generation?  
 ii) **Perform** a Chi Squared test to determine if this trait follows classic Mendelian genetics. Use the equation page from the AP test to evaluate.

C. **Propose** one way the environment might influence the phenotypes observed in the coyotes.

2. The following pedigree is available for the questions below:



A. **Determine** whether the pedigree demonstrates autosomal or sex-linked inheritance. **Justify your answer.**

B. **Provide the genotype** of the following individuals in the diagram.

i. A

ii.B

C. **What was the probability** of female B and her male partner producing an affected:

i. female. **Justify your answer.**

ii male. **Justify your answer.**

- D. **Explain why** sex-linked traits do not follow classic Mendelian genetics.
3. Modern genetic testing can trace the ancestry of the maternal line in humans but not the paternal line.
- A. **Describe** how this is possible.
  - B. **Explain the endosymbiotic theory** and how it relates to this type of inheritance pattern.
  - C. Chloroplasts possess a circular DNA strand that encodes for over 50 different genes.
    - i. **Propose** why traits coded for by genes on chloroplasts do NOT follow mendelian genetics.
    - ii. **Propose** one advantage of chloroplasts having their own DNA in terms of the ability of a plant cell to respond to the environment.

### 3.B.1

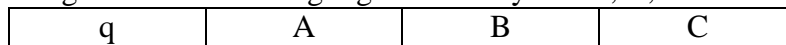
#### 3.B.1

**“Gene regulation results in differential gene expression, leading to cell specialization.”**

1. There are more than 200 different cell types in the human body ranging from neurons to epithelial cells lining the lungs. Barring mutations, each of these cells use the same set of DNA.
- A. Describe how this specialization can occur when each cell has the same DNA?
  - B. Consider the statement: “Multicellular organisms with cellular specialization have a fitness advantage over unicellular organisms.”
    - i. In the biological sense, what is meant here by “fitness”?
    - ii. Do you agree with the statement? Provide evidence to support your answer.
    - iii. Explain how a unicellular eukaryotic cell creates a similar “division of labor” as we see in multicellular organisms.
    - iv. Propose two reasons as to why large organisms tend to be multicellular.
2. It is now thought that between 1 and 2% of all inheritable human disease is caused by mutations in the regulatory sequences of genes, as opposed to in the gene itself.
- A. Compare and contrast regulatory sequences of DNA and regulatory genes. How are they similar and how are they different.
  - B. Explain how an error in a regulatory sequence can be as damaging as a mutation in the gene itself.
3. Regulatory proteins can stimulate or inhibit DNA transcription in prokaryotes, viruses, and in eukaryotes.
- A. Explain two ways in which a regulatory protein can promote DNA transcription. Use appropriate vocabulary.
  - B. Explain how a repressor negatively controls gene expression

4. A prokaryotic cell is known to create a series of enzymes involved in the synthesis of a particular amino acid called X. The genes that code for each of these enzymes are referenced by genes A, B, and C. A schematic of this region of DNA is represented below:

Figure 1: DNA coding region for enzymes A, B, and C



In an attempt to study the regulation of this transcription unit, scientists examined the impact of a number of molecules on the transcription of enzymes A, B, and C. Their results are below:

Molecule	Concentration of molecule	Cellular concentration of enzyme A (mg/uL)
N	0.5 uM	3.4
N	3.0 uM	3.3
Amino acid X	4 mM	3.4
Amino acid X	7 mM	0.3

A. What is region “q” depicted in figure 1? Explain it’s function in the DNA? Use appropriate vocabulary.

B. Scientists believe that molecule “N” is a repressor protein coded for by a regulatory gene. Propose why the cellular concentration of enzyme A remains relatively unchanged despite the higher concentration of repressor protein N. Justify your answer.

C. It has been previously reported that amino acid X alters the conformation (shape) of repressor protein N when bound to it.

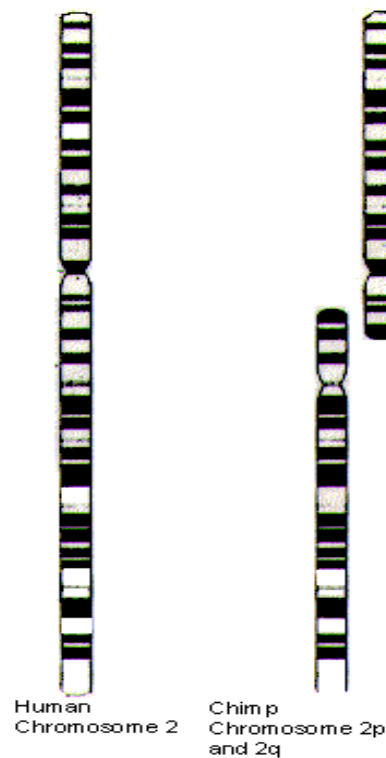
i. Propose how the higher levels of protein X could cause a drop in the synthesis of enzyme A. Be sure to include proper vocabulary.

ii. Is the transcriptional regulation here an example of positive or negative genetic control? Justify your answer.

iii. Explain how this method of genetic regulation allows the cell to function efficiently.

5. Human cells have 46 chromosomes while chimpanzee cells have 48 chromosomes. In fact, each chromosome looks very similar – see below.

Figure 1: Human vs. Chimp DNA



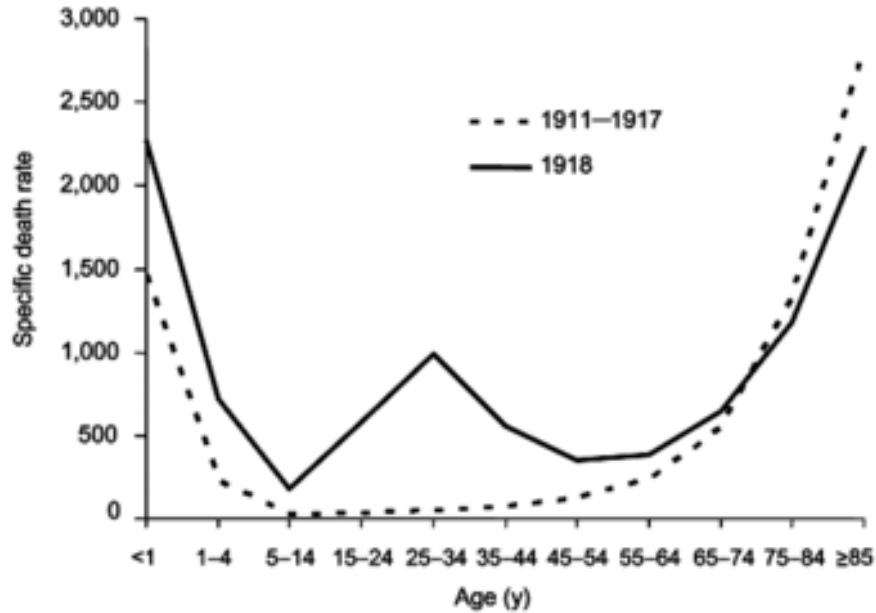
- A. Provide a genetic explanation for the phenotypic differences between humans and chimpanzees given that they have extremely similar DNA (some experts classify the DNA as roughly 98% similar).
- B. Many plants have chromosome numbers similar to humans and chimps. Is the chromosome number a good indicator of organisms sharing an evolutionary ancestor? Justify your answer.
6. Environmental factors influence genetic regulation.
- A. Explain how the presence of lactose outside a bacterial cell acts to induce transcription of the Beta galactosidase enzyme that breaks down lactose. Carefully explain the role of the inducer, the repressor, and the operator.
- B. Is the lac operon an example of positive or negative control of transcription regulation? Justify your answer.
- C. If a bacterium had a mutation in the regulatory gene that codes for the repressor, how would this impact the production of B galactosidase?

- D. Consider the statement “the gene that codes for the repressor protein is likely to be highly conserved within the prokaryotic world”. Do you agree? Justify your answer in terms of evolutionary fitness.
7. Compare and contrast prokaryotic vs. eukaryotic gene expression. Provide one similarity and one difference between each. Be sure to reference both cell types in each comparison.
8. Regulation of cellular activity can occur in many ways including transcriptional regulation and enzymatic regulation.
- A. Which type of regulation is likely to be faster; enzymatic or transcriptional control? Justify your answer.
  - B. The reproductive cycle of a woman is governed by hormone amounts that change significantly with the advent of puberty. Is this likely the result of enzymatic or transcriptional regulation? Justify your answer.

### 3.B.2

#### “A variety of intercellular and intracellular signal transmissions mediate gene expression”

1. Cells use intracellular and intercellular signals to maintain homeostasis.
- A. **Describe the difference** between these two types of signals.
  - B. **Explain** how these two signaling methods are coupled to cause a change in gene expression.
2. In 1918, the Spanish flu caused the death of roughly 1-3% of the world’s population. Most flu viruses disproportionately kill people with weakened immune systems such as the elderly or very young because their immune cells do not make enough particular cytokines, chemicals that stimulate the rapid division of cells involved in the immune response. The production of too many of these particular cytokines is known to create an elevated immune response that itself can cause elevated fevers and death. The graph below shows the number of deaths in each age group from the 1918 Spanish flu along with the deaths in each group from flu viruses present from 1911-1917.



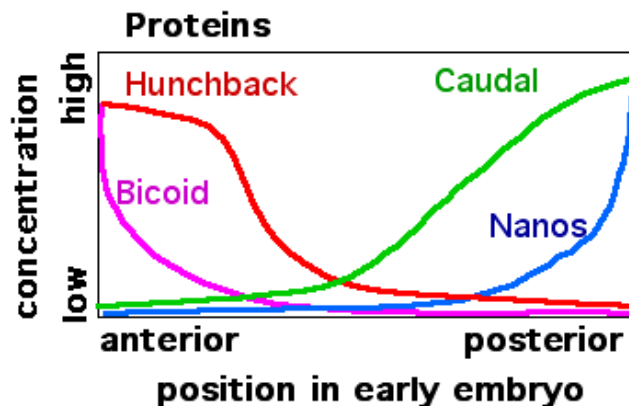
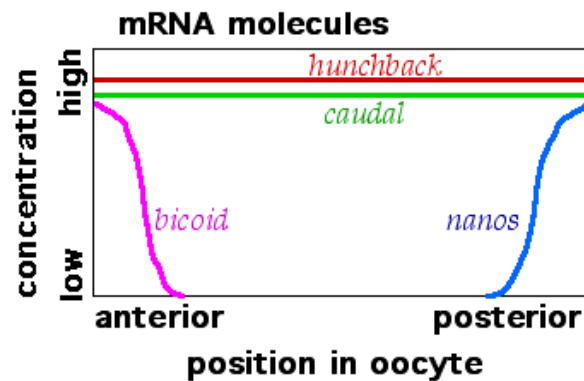
- A. **Which** age groups were most affected by all the viruses?
- B. **Which** age group was unexpectedly affected by the 1918 spanish flu?
- C. Starting with the intercellular cytokine signal and ending with the replication of the desired immune cell.
- Propose** a series of steps that outline the specific events that would need to occur to cause a change in gene expression of the targeted cell.
  - Various genes are responsible for encoding for a family of proteins known as cyclins. **Explain the role** of cyclins in regulating the cell cycle and whether the cytokine signaling pathway described above would likely upregulate or downregulate the expression of the cyclin genes.
- D. **Theorize** in what way the cytokine regulation system failed in healthy individuals. **Was this** an example of positive or negative feedback? **Justify**.

3. HOX genes are crucial for the development of multi-cellular organisms. These genes are highly conserved, so much so that when a normal HOX gene from a fruit fly is replaced with one from a chicken, the fruit fly will still develop normally! Below is a series of HOX genes and the activity they stimulate in fruit fly development:

HOX gene	Activity Stimulated	Stage of development when HOX encoded protein is in high abundance
A	limb development	late
B	apoptosis	late
C	cephalization	early

- A. **Propose why** HOX genes are so highly conserved across many species.
- B. Consider the statement “The protein encoded by HOX gene A makes up the structure of the legs of the fruit fly”
- Do you agree** with this statement? **Justify your answer.**
  - Propose a mechanism** as to how the up-regulation of a HOX gene can cause the up-regulation of other genes. **Use appropriate and specific vocabulary**
- C. **Which** of the HOX genes is likely activated by proteins encoded by mRNA left from the mother? **Justify your answer.**

4. The early fruit fly embryo contains mRNA left behind in the oocyte from the mother. These mRNA strands (hunchback, caudal, bicoid, and nanos) encode for proteins that help differentiate the anterior and posterior portions of the fruit fly. The tables below show the relationship between the amounts of these materials:



- What** is an oocyte?
- Describe** the impact of the translation of the bicoid mRNA on the translation of the caudal mRNA. Why is this interaction so important?
- Provide evidence** from table 1 that bicoid mRNA encodes proteins that stimulate the synthesis of hunchback proteins and not the other way around.

D. **What** would be the phenotype of a fruit fly that had a mutation in the bicoid mRNA? **Justify your answer.**

E. **Propose how** this type of regulation allows for the development of segmented bodies.

### 3.D.2 Cells communicate with each other through direct contact with other cells or from a distance *via* chemical signaling.

1. Cells communicate with each other a number of different ways: directly, locally, and through the use of hormones.

A. Describe the differences between these three methods of communication.

B. Provide a specific example of:

i) Direct communication between two plant cells.

ii) Hormonal communication between the brain and the target cells.

C. Contrast hormone production in plants vs. in animals

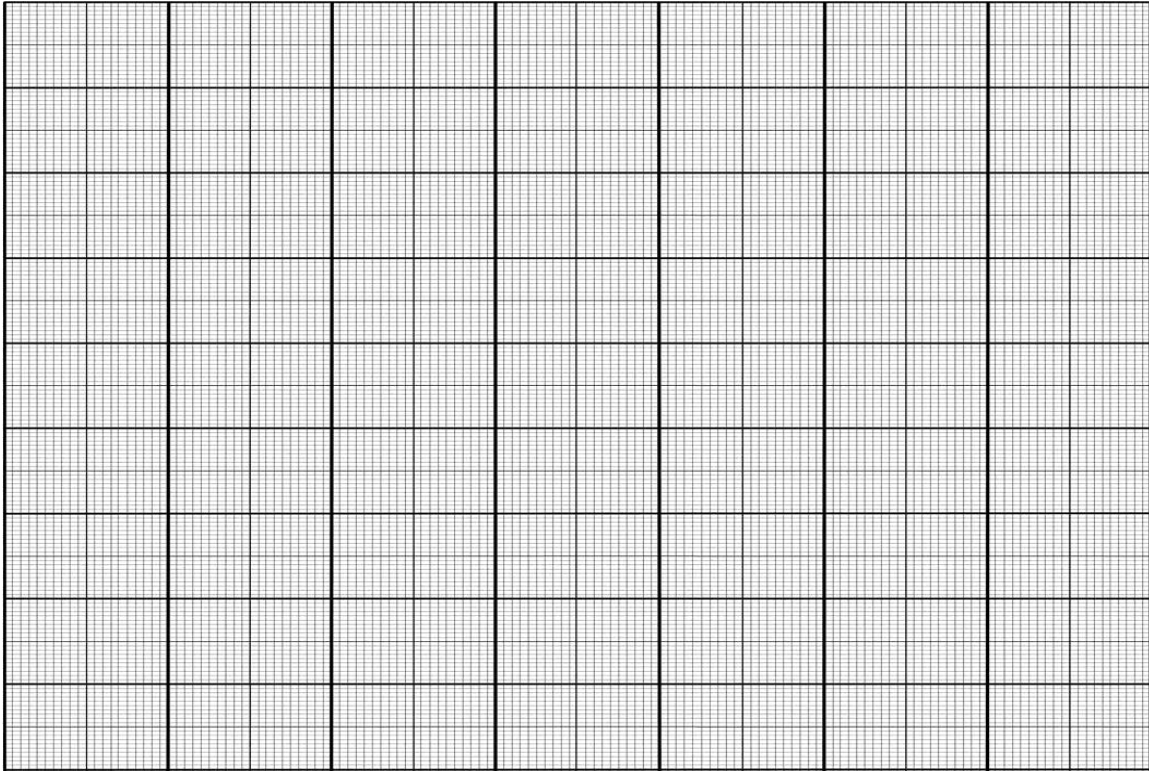
### 3.D.3 Signal transduction pathways link signal reception with cellular response.

1. A chemical in grapefruit juice is now known to have an impact on the activity of the enzyme CYP3a4 present in the liver. CYP3a4 activity can be measured by examining its ability to degrade the drug simvastatin which is used to treat cholesterol. The table below shows the amount of simvastatin present in the blood of a patient if the patient takes the drug with grapefruit juice or without grapefruit juice. It is thought that a chemical in grapefruit juice acts as a ligand to initiate a cell signaling pathway that governs the behavior of the CYP3a4 enzyme.

	Simvastatin taken with grapefruit Juice	Simvastatin taken without grapefruit juice
Blood serum level of simvastatin after 1 hour	12 ug/mL	1.3 ug/mL
Blood serum level of simvastatin after 2 hours	6 ug/mL	0.5 ug/mL
Blood serum level of simvastatin after 3 hours	0.2 ug/mL	0.2 ug/mL

A. **Create** a line graph below that illustrates the results of the experiment. Clearly label both axes.





**B. Compare** the three phases of signaling (reception, transduction, and response) - clearly describing what happens in each phase.

**C. Choose** a specific reception and transduction pathway and **describe** how a cellular response is initiated when the grapefruit chemical acts as a ligand.

### **Answers**

#### **3.A.1**

*1a. It was known that genes are contained in the nucleus. The stain binds to DNA, therefore DNA is the nucleus. Therefore there is the likelihood that DNA comprises the genes.*

*1b. Different species have different structures and behaviors and therefore very probably different gene types and numbers. Staining of different degrees would support this.*

*1c. Sex cells should have half the genetic material of somatic cells based on previously discovered principles of reproduction by fusion of gametes with half the genetic material.*

*2. Heat treating A lyses the cells but does not alter the DNA. The part of the DNA that makes A deadly is taken up by strain B during incubation transforming it into deadly bacteria. Once injected, these bacteria then kill the rat.*

*3. In the first experiment, DNA from A transforms B strain causing B to become virulent. The DNA is available to B once the cells of A are lysed. In the second*

experiment, high heat denatures DNA of A deactivating genes that would be deadly. Any DNA taken up by B would therefore have no effect on the rats.

4. Protease – 100%, RNAase – 100%, DNAase – 0%. DNA carries the genes that make strain A deadly. Removing RNA or proteins has no effect on the 100% mortality rate as the RNA and proteins can be transcribed by still in tact DNA. Once DNA is destroyed, however, none of the appropriate proteins can be made, making strain A no longer virulent.

5. Phosphorus is present in DNA but not protein. Sulfur is present in proteins but not DNA. This allowed them to distinguish between the parts of the virus that had been transferred to the bacteria. The labeled phosphorus in DNA was found in the bacteria while the labeled sulfur protein was found in the supernatant generated after centrifuging the infected bacteria. Had nitrogen been used, radiolabeled nitrogen would have been found both in the bacteria and the supernatant. This is because nitrogen is a component of both DNA and proteins. Therefore, it would have been impossible to distinguish between DNA and proteins.

6. The injected DNA would have been absorbed, broken down and excreted by the body. Whole genes are unlikely to have been incorporated into the DNA of a single cell, let alone enough cells to turn the duck brown. Gene therapy using modified viruses may have had more success. Hypothetically, in this process, the gene(s) coding for pigmentation is delivered to skin cells where the virus then delivers the gene and incorporates it into duck genome. This gene is expressed by the cell and produces brown pigmentation.

7. Chargaff discovered the principle that C and G and A and T were always found in equal amounts in DNA indicating that they came in pairs. Wilkins developed very pure crystal samples of DNA with aligned strands. This made it possible for Franklin to make the X-ray crystallographs that indicated a helical structure. Pauling also theorized a helical structure (a single helix) but had also used physical modeling to create models of biological molecules that inspired Watson and Crick to use the same method.

8. In the second generation, neither light nor heavy DNA is found. This indicates that both heavy parent strands have been combined with strands made from normal weight medium. In the third generation, the light strand of each intermediate parent molecule has been combined with light medium making it a fully light strand. Intermediate weight DNA still exists, owing to the presence of the two original heavy strands but in decreasing proportion. This proportion continues to decrease in generation four, as more light DNA medium is used.

9.

Generation of Bacteria	Mass of DNA by proportion of sample (%)		
	Heavy	Intermediate	Light

1	100	0	0
2	50	0	50
3	25	0	75

*In generation two, each heavy parent strand recombines once DNA has replicated and new molecules using only nitrogen-14 are made. This provides the 50:50 split heavy to light. This is repeated in the third generation but now, the relative proportion of heavy DNA is decreased as more DNA is made with only light nitrogen available for synthesis.*

10. A. central dogma – most eukaryotes and prokaryotes.

B. RNA used to carry code and produce polypeptides – found in some viruses, e.g. polio.

C. RNA used to make DNA in a host cell that then produces RNA copies which are subsequently translated to make proteins – retroviruses.

11.

Property	Nucleic Acid	
	DNA	RNA
Base types	A, C, G, T	A, C, G, U
Base pairing	A-T, C-G	A-U, C-G
Molecular shape	Double helix	Single strand, multiple shapes dependent on function
Location in eukaryotic cells	Nucleus only	Nucleus and cytoplasm
Sugar molecule	Deoxyribose	Ribose
Method of production	Semi-conservative replication	Transcribed from DNA (most common) or RNA (some viruses)
Subtypes and functions	DNA - Code carrier/template for RNA, genetic regulation	mRNA - code carrier/template for proteins, rRNA – catalyzes polypeptide synthesis and provides structure to ribosome, tRNA – transports amino acids to ribosome, small RNA's e.g. iRNA - regulation of transcription

12.

TAC	CCG	CCT	AAT	CAG	TGC	TTC	CTT	TAT	CCG	CAT	GCC	CGG	ATC	GGA	ATT
AUG	GGC	GGA	UUA	GUC	ACG	AAG	GAA	AUA	GGC	GUA	CGG	GCC	UAG	CCU	UAA

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AP Biology

Big Idea

DNA  
 mRNA  
 cuts  
  
 processed  
 mRNA  
 Polypeptide

EXON	INTRON	EXON	INTRON	EXON
------	--------	------	--------	------

mG	AUG	GGC	GGA	UUA	GAA	AUA	GGC	CCU	UAA	AAAAAAAA
	Met	Gly	Gly	Leu	Glu	Ile	Gly	Pro	Stop	

13.

A) Proteins and DNA both contain C, H, and O but proteins contain S while DNA contains P. Additionally, proteins consist of monomer amino acids bound together while DNA contains monomer nucleic acids. Functionally, proteins act structurally or physiologically while DNA provides the code for the ordering of amino acids in a protein.

B) The new culture will contain both R and S type bacteria.

C) Avery treated the lysate with proteases that destroy proteins and then mixed the lysate with the R type bacteria. Transformation still occurred. Since the proteins were destroyed, any transformation must have been due to the DNA. Conversely, when the DNA was destroyed using a nuclease, the transformative properties of the lysate were lost.

D) None of the radioactive S would be passed on to the colony as the transformative agent is DNA not protein. The colony would be non-radioactive.

14. A) PCR is used to amplify the DNA in vitro. The DNA strands are separated using heat and replicated using a heat tolerant DNA polymerase. The strands are then permitted to cool and allow for annealing.

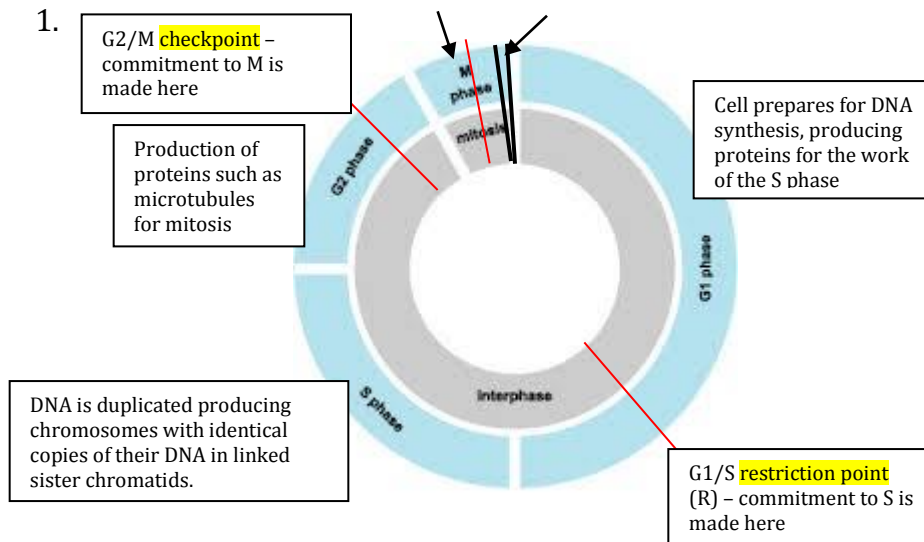
B) The strands of DNA are held together by weak hydrogen bonds and can be easily separated by temperature or enzymatically. Each strand then acts as a template for the new strand. Proteins cannot be directly replicated as no part can serve as a template for replication.

C) The denaturation occurs via heat in PCR. In biological systems it is done via an enzyme – DNA helicase.

D) In biological systems, there is a replication fork that moves away from the lagging strand start point due to the 5'-3' nature of the DNA replication. Therefore the lagging strand fragments must be joined later. In PCR, there is no replication fork and therefore no leading/lagging strand.

### 3.A.2

1.



2.

a) True – Deactivation of the inhibitory protein requires phosphorylation. Phosphorylation generally requires ATP as a source of the phosphate group. ATP is therefore probably required to allow the cell cycle to proceed.

b) False – cyclins are required for the activation of the Cdk's, hence their name. Their concentration is irrelevant to their activity, unlike many enzymes.

c) True – because Cdk's are dependent on cyclins for their activity, an allosteric regulation is indicated. Only in the presence of cyclins can the enzyme phosphorylate the inhibitory protein and allow R point to be crossed.

3. Platelets gather at a wound to initiate blood clotting. Concurrently, however, they produce platelet derived growth factor, a protein that binds to kinase receptors in the skin cells. This initiates an internal cascade inside the cell, releasing cyclins and causing the cell to enter the cell cycle and proliferate, thereby healing the damaged tissue.

4a. The high concentration of HER2 receptors make these cells more susceptible to growth hormones present in the body at normal levels. These cells are more likely to bind the growth hormone and initiate the cascade that turns on the cell cycle.

b. However, alone, this will not cause cancer as checkpoints are in place throughout the cell cycle. But if these checkpoints are damaged, the cell will proceed with the cell cycle, in effect, having the brakes removed from the process. Damage to tumor suppressor genes such as those associated with RB production is an example of such an occurrence.

5. A) In G1 phase, the cell grows and synthesizes proteins necessary for regular cell function. In S phase, the DNA is replicated in preparation for division.

B) Without the P53 protein, the cell cycle cannot be properly halted at the G1/S phase checkpoint through the mediation via P21. Consequently, the cell may enter S phase with mutated DNA causing cancer.

C) Cyclins are combined with and activated by the cyclin dependent kinases to make the MPF (M-phase promoting factor). This factor accumulates throughout G2 phase and promotes the degradation of the nuclear envelope to begin mitosis. Cyclins are then degraded during mitosis.

D) Apoptosis is the process by which the cell induces it's own death. P53 does this as it is a response to cell damage and therefore protects the organism by destroying itself before the mutation gets passed on through S phase replication and division.

### 3.A.3

1.
  - a. Yes, the allele locus is on a non-sex chromosome.
  - b. The primary structure of a protein is the polypeptide chain encoded for by the DNA. The secondary structure (either a alpha helix or beta pleated sheet) is

created as the protein folds on itself with the assistance of hydrogen bonds and hydrophobic interactions. If a hydrophobic amino acid were substituted for a hydrophilic one, the primary chain would not properly form the secondary structure due to the disturbance of the bonds.

c. **Ss x Ss, ss x ss, Ss x ss**

d. I)  $0.50 \times 1 = 0.50$  or 50% II) 0.50 or 50%

2. a. Flower location and seed color. They will sort independently because they are on different chromosomes. Plant height is on the same chromosome as flower location and would only independently assort if they were widely separated on the chromosome.

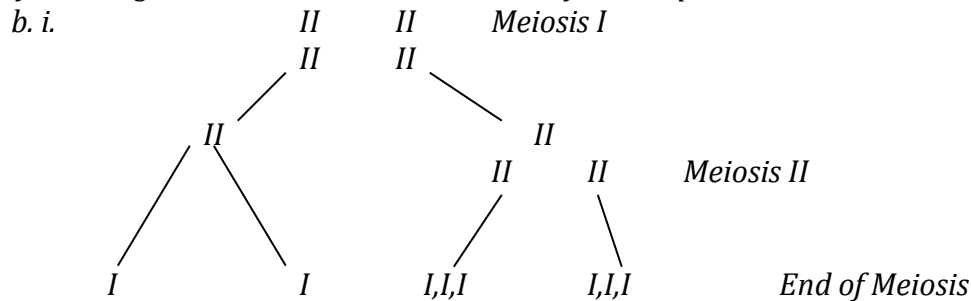
b. i. The phenotype would be axial and yellow. The genotype would be AaYY. The student show either mathematically or with a Punnett square how they obtained there answer. For example:

	AY	aY		A = axial	a = terminal
ay	<b>AaYy</b>	<b>aaYy</b>		Y = yellow	y = green

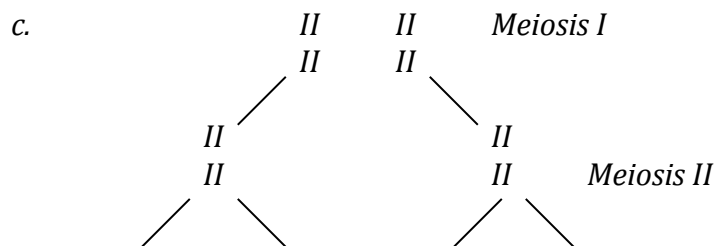
b. ii. 9/16. Students may show Punnett square or determine it mathematically.

*Heterozygous dihybrid for both alleles produces the 9:3:3:1 ratio.*

3. a. Occurs when sister chromatids fail to separate and segregate in meiosis II or if homologous chromosomes in the tetrad fail to separate in meiosis I.



b. ii. Gametes either by  $N = 1$  or  $N=3$



I
I
II
I
End of Meiosis

I
I
I

Probability = 50%

- d. The woman might be counseled to try pregnancy as:
- i) Unlike her sister who is older and bears a greater risk of non-disjunction, she is still not within the risk group.
  - ii) Non-disjunction is not a heritable trait so the fact that it occurred within the family does not incur extra risk to her.

### 3.A.4

1.
  - a. Since the pairing was between two homozygous coyotes, 100% of the coyotes would have the large phenotype and the heterozygous dominant genotype.
  - b.
    - i. Since the breeding would be between two heterozygous individuals, one would expect that 75% of the animals would have the dominant phenotype with 25% being recessive yielding a 3:1 ratio
 

		L	l
Ll	x Ll	→	
		L	LL
		l	Ll
			ll
    - ii. Use the chi square equation and obtain a result of 14.93. With one degree of freedom, there is a greater than 10% chance that this data does NOT follow the proposed mendelian inheritance pattern.
    - c. The diet of the eastern and western coyote may be quite different resulting in different observations of their size – independent of genetic expression.
2.
  - a. The pedigree shows a sex-linked pattern. This can be inferred due to the prevalence of occurrence of this disease in males. Carriers are not shown in the diagram but can be inferred as the expression of the phenotype of the disease skips generations.
  - b.
    - i. A must be  $X^N Y$  because he is unaffected. The y chromosome does not carry an allele for the trait.
    - ii. B must be  $X^N X^n$  as she has managed to pass a recessive carrier X chromosome to one of her sons.
  - c.
    - i. 0% as the male – being that he does not express the gene – must pass on a dominant X to the female offspring.
    - ii. 50% as the female – being heterozygous – could pass on the recessive or dominant trait with equal likelihood.
  - d. The male Y chromosome is not a true homolog of the X, it only carries a few genes, therefore it contributes little to the expression of some traits.
3.
  - a. Mitochondria possess their own DNA and are only found in the egg gametes of the female so all mitochondrial inheritance is through the female.
  - b. The theory proposes that mitochondria and chloroplasts were prokaryotes that were engulfed by eukaryotic cells. Since they offer evolutionary advantage to the host cell, they have been conserved in the cells. Without their own DNA

*and their presence in our eukaryotic cells, they could not trace lineage in this fashion.*

*c. i. Since the DNA is circular and NOT arranged in chromosomes, there are no homologs so the ideas of segregation and independent assortment do not apply.*

*c. ii. Since chloroplasts have their own genome, they can reproduce on their own and adapt to changing conditions such as increased sunlight or nutrient availability faster than the host plant cell.*

### **3.B.1**

1. 

*A. Specialization is possible due to the inactivation of genes in certain cells and activation of others in different cells. Each cell responds to a different set of signals that in turn regulate the expression of genes.*

*B. i. Fitness is a measure of how well an organism's traits make it suitable for its environment. Individuals with a high fitness will survive to reproduce and their genes will be well represented in the overall gene pool. In this sense, the term would mean that cellular specialization provides for a high level of fitness*

*B. ii. A student may agree or disagree. Those who agree should cite evolutionary evidence along the lines of eukaryotes succeeding prokaryotes and forming the largest group of organisms on the planet. Those who disagree might cite the fact that bacteria have survived and are still well represented.*

*B. iii. Eukaryotic cells divide responsibilities among different organelles.*

*B. iv. Unicellular organisms are limited in size due to the surface area to volume ratio of the cell. If this becomes too small, the cell cannot maintain homeostasis. Secondly, the specialized cells provide for the adaptability needed for a larger organism to survive in the macroscopic world.*
2. 

*A. Regulatory genes code for proteins that act as regulatory molecules (either inducers or repressors) for a transcription sequence on the same or another chromosome. A regulatory sequence is an area of DNA upstream of the gene loci that houses the promoter, enhancer, and operator portions that help regulate transcription.*

*B. Damage by mutation to a regulatory gene will cause either overly active or overly inactive expression of a gene – both of which can lead to lethal disease conditions.*
3. 

*A. First, a regulatory protein can bind to a previously active repressor protein thereby causing a conformational change which causes it to release and allow for RNA polymerase to attach and transcribe. Secondly, a regulatory protein may act as an inducer by binding to the promoter area and providing a more favorable binding of the RNA polymerase enzyme.*

*B. A repressor, either when attached to a ligand or in its free form, can bind to the operator and prevent RNA polymerase from attaching to the DNA.*
4. 

*A. Region q is the promoter region which also houses the operator. This is a regulatory stretch where inducers or repressors will bind to either stimulate or inhibit transcription.*



*B. Some repressors are constantly made in small doses in an inactive form. Since increasing the amount of it caused no change in transcription, it is likely that it needs a ligand to bind to it to cause it to activate and suppress transcription.*

*C. i. Amino acid X could be the ligand that binds to the repressor thereby shutting the transcription off. This would make sense as amino acid X is the product of the pathway and this would be an example of product inhibition along the lines of the trp operon.*

*C. ii. This would be negative control as the repressor ligand complex acts to inhibit transcription.*

*C. iii. By shutting down the transcription of genes that make a product when that product is already in high abundance allows the cell to conserve resources and adapt to the changing environment.*

5. 

*A. Although the genome is similar, the expression does not need to be and is evidently not based on the phenotypic differences observed.*

*B. Absolutely not, chromosome number is far less important than is the conserved portions of the genome between species.*
6. 

*A. In the lac operon, the gene that codes for the enzyme B-galactosidase is shut off by a repressor molecule when lactose is not present. When lactose is present, allolactose is produced which binds allosterically to the repressor changing its conformation. This allows an inducer molecule cAMP to aid the binding of RNA polymerase to the DNA which allows for transcription of the gene coding for the lactose catabolism enzymes.*

*B. It really provides an example of both. The inducer effect of cAMP is positive regulation, but the normally active repressor is an example of negative control*

*C. The enzyme would be made unnecessarily – decreasing the fitness of that bacteria.*

*D. I agree, without this gene, the bacterium would spend energy with no profit. It must be able to adapt to the changing surroundings.*
7. 

*Prokaryotic regulation and eukaryotic regulation both occur via promoters, operators, repressors and inducers. However, eukaryotic regulation is more complex using a wide variety of transcription factors not found in prokaryotes.*
8. 

*A. Enzymatic regulation is faster because the regulation takes place among proteins that already exist and are serving as regulatory checkpoints. Transcriptional regulation requires the production of new proteins to cause the change.*

*B. The hormonal regulation is likely caused by transcriptional change as new proteins must be made, as opposed to up or down regulating enzymes just waiting for a chance to finally do something!*

### **3.B.2**

1. 

*A. Intercellular signaling involves the secretion of a chemical that will bind specifically to a cell with the correct receptor that is either local or in a*

*different part of the body. Intracellular signaling involves a pathway within the cell that stimulates a cellular response.*

*B. An intercellular signal reaches a receptor on a cell membrane which induces an intracellular signaling cascade, often involving kinases or secondary messengers, causing a change in gene regulation by activating transcription factors, repressors, enhancers, etc.*

2. A. Youngest and oldest

*B. The 25-34 age group – the group with normally the highest immune response.*

*C.*

*i. An immune cell secretes a cytokine that specifically binds to a specific receptor on another immune cell. The receptor, once bound with the cytokine, initiates a signaling cascade resulting in the activation of transcription factors that enable the transcription of particular genes.*

*ii. Cyclins regulate the cell cycle. For instance, in order for a cell to enter S phase from G1, the cyclin levels must rise to bind to CdK (cyclin dependent kinases) to create a complex that stimulates S phase DNA replication and mitosis. Post-mitosis, the level of cyclin drops significantly, allowing the cell to continue and develop in G1 phase. The effect of this cytokine signaling pathway is likely to up-regulate cyclin gene expression to promote the movement of cells from G1 to S phase to initiate cell division of immune cells to help fight the infection.*

*D. Since these individuals had active immune systems, the cytokine mediated response would be significant. A proliferation of cytokines would cause a further proliferation of cell division and production of new cytokines. In essence, this would cause a cascade of cytokines that would present as an uncontrollably high fever – causing lethality. Individuals with less active immune systems produced a more proportionate response and thus survived.*

3. A. Without them, the proteins that activate the transcription of proteins that enable differentiation of cells, would be absent thereby preventing the organism from properly differentiating and developing. For instance, cells in the mesoderm need instructions as to which genes and the time of expression in order for them to form different muscles.

*B.*

*i. NO – the HOX gene encodes a regulator protein that acts to up-regulate specific expression of the gene that codes for the proteins that make up the legs.*

*ii. A HOX gene, once activated for expression itself, will produce proteins that act as transcription factors that bind to enhancers to serve to enable expression of developmentally appropriate genes.*

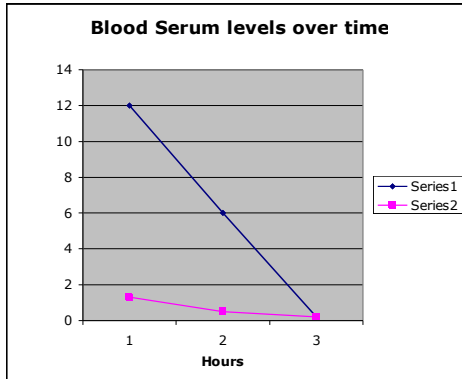
- C. HOX gene C, because it's action is needed early in the developmental process. For example, it may be activated by the bicoid protein encoded by the mother to initiate the development of the anterior part of the embryo.*
4. *A. An unfertilized egg. Haploid. The cell is polarized in that the mRNA from the mother that codes for various developmental proteins are not equally distributed throughout the cell.*  
*B. Bicoid proteins inhibit translation of caudal proteins, this allows the anterior section of the embryo to develop.*  
*C. The hunchback mRNA is present in equal amounts throughout the oocyte. Bicoid mRNA is only found in the anterior side, thus after fertilization, the bicoid protein is synthesized triggering the synthesis of hunchback. If hunchback did not need bicoid for activation then it would be expressed throughout the oocyte.*  
*D. The phenotype would have two posterior ends. This is because without bicoid, there would be no repression of caudal which stimulates posterior development and under expression of the hunchback protein which stimulates anterior development.*  
*E. By using proteins to regulate gene expression, genes in one region of the embryo are activated by a chemical signal which in turn represses genes that would code for proteins appropriate for another segment of the organism.*

### **3.D.2**

- A) Direct communication occurs between cells connected to each other. These interactions allow for quick changes to occur between cells. Local communication occurs between cells that are in close proximity to each other but not touching. These communications are also quick. Hormonal communication occurs over long distances and generally provide slower changes such as those that govern long term growth or reproductive cycles.*  
*B) i) Plasmodesmata are junctions between plant cells that allow for quick diffusion of solute or hormones necessary for communication.*  
*ii) Growth hormone is released by the anterior pituitary gland, moves through the blood, and attaches to receptors on the osteocytes and chondrocytes to stimulate bone and cartilage development.*  
*C) Hormone production occurs cellularly in plants as they have no glands. Animals use glands for hormone production and a circulatory system to transport the hormones.*

### **3.D.3**

1.



A)

*B) Reception – the ligand from outside the cell attaches to a receptor on the cell membrane which then activates a protein kinase or secondary messenger. Transduction – a phosphorylation cascade develops between protein kinases resulting in the activation or deactivation of a transcription factor which causes a will then act to enhance or inhibit transcription.*

*Response – the transcription factor either aids to promote DNA transcription of a gene (positive control) or acts to repress the transcription (negative control). In a cytoplasmic response, the activated protein either stimulates or inhibits a particular pathway.*

*C) The ligand binds to a g-protein linked receptor which then activates G-protein by phosphorylation of the G-protein by GTP. This results in a phosphorylation cascade involving protein kinases which activates a protein involved in a particular cellular response.*