CHAPTER 1: GENOMES AND THE FLOW OF BIOLOGICAL INFORMATION

1.1 THE ROOTS OF BIOLOGY

1. For each of the terms below, fill in the table with the appropriate information.

Term	Definition	Importance to life
Cell Membrane	*Physical barrier that separates an individual cell from its environment*	*Allows an individual cell to maintain a unique internal environment*
Nucleic Acid	*Series of nucleotides that contains the instructions for life*	*Organisms must have a way to store and use the information with which to create their characteristics*
Replication	*Process by which a complementary strand of DNA is created*	*Organisms pass information to the next generation of cells and individuals*
Energy	*The ability to do work*	*Drive all biological processes of life*
Polymer	*Repeating unit of molecules*	*The major biological molecules are polymers made of smaller repeating units*

2. What evidence exists to suggest that all life was derived from a last universal common ancestor (LUCA)?

   When we compare the great diversity of organisms that lives today we find that they are all made of the same core building blocks: nucleic acids, proteins, lipids, and carbohydrates.

3. Describe the meaning of each of the following terms with regard to the structure of DNA.

   a. Polymer – *DNA is made of repeating units of the nucleotides A, T, C, and G.*
   b. Complementary base pairing – *the two strands of DNA are linked by specific hydrogen bond-mediated base pairing between the nucleotides A-T and C-G*
   c. Directionality – *the two strands of DNA have antiparallel orientation where one strand is denoted 3' to 5' and the other 5' to 3'.*
   d. Genome – *the complete sequence of nucleotides comprising an organism's DNA.*
   e. Gene – *a region of DNA that controls a discrete, hereditary characteristic. Commonly it specifies the production of one functional product.*
   f. Chromosome – *a single DNA molecule packaged into a functional unit*

1.2 THE GENOME: A WORKING BLUEPRINT FOR LIFE

1. What is meant by molecular conservation and why is it important?

Molecular conservation refers to the fact that the DNA sequences of different organisms can have a great degree of similarity. This similarity is important because it suggests that the functions of different segments of DNA have similar functions and were derived from a common ancestor. The comparison of genomes gives us a mechanism to both understand the functions of different segments of DNA and determine relationships among organisms.

2. What relationship exists between genome size, gene number, and organism complexity? Give an example to support your answer.

No correlation. Zebrafish and lungfish are pretty similar in phenotype, but zebrafish has 2000 Mbp in its genome while lungfish has 130,000 Mbp. Drosophila, C. elegans, and humans have similar genome sizes but differ in their complexity.

Challenge Question

3. Explain why 'biological complexity comes from more than just the genes of an organism'.

The number of genes alone cannot explain complexity. It also comes from how many products are produced from one gene, and what gene regulation is at play.

1.3 BRINGING GENES TO LIFE: GENE EXPRESSION

1. What steps are necessary for the information contained in DNA to be used to direct the life of an individual organism?

The DNA must be transcribed into RNA. The RNA may then have a direct function or it may be translated into protein.

2. Fill in the following table to highlight the similarities and differences in DNA replication versus transcription.

Feature	Replication	Transcription
Polymerase required	*DNA polymerase*	*RNA polymerase*
Mechanism for adding the correct base	*Complementary base pairing*	*Complementary base pairing*
Base complementary to C	*G*	*G*
Base complementary to A	*T*	*U*
Portion of genome involved	*All*	*Discrete genes*

3. Explain the difference between coding and non-coding RNA.

Non-coding RNA is functional as an RNA and is not translated into protein. Coding RNA is an intermediate in the synthesis of protein from DNA.

4. Describe the table depicted in figure 1.13?

   The table provides the amino acids encoded by each three base pair codon in DNA. The significance is that, for all organisms, the genetic code is conserved.

5. It has been estimated that the human genome consists of approximately 30,000 genes. Describe some of the ways in which it is possible for the set of functional RNAs and proteins to number over one million.

   Each transcribed RNA and translated protein can be modified in several different ways to produce more than one functional product. Additionally, due to small size and low expression levels, many genes have gone undetected until recent technological advances revealed them.

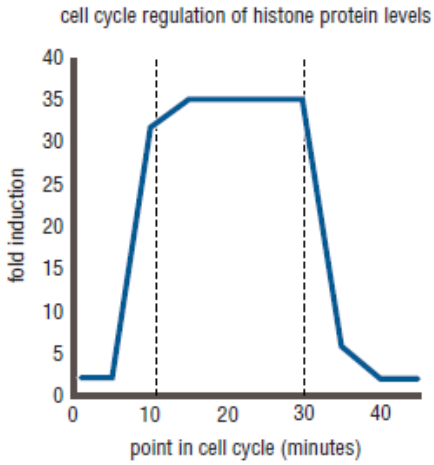
1.4 REGULATING GENE EXPRESSION

1. What is meant by the phrase 'gene expression is regulated in time and space'?

   Regulation in time refers to the concept that, even within one cell, different genes may be expressed at different times to respond to different environmental conditions. Regulation in space refers to the concept that, although every cell in a multicellular organism contains a copy of the entire genome, the portions of the genome used by different cells in different parts of the organism varies. This is what makes each cell type unique.

Challenge Questions

2. Histone proteins are expressed in cells in the specific pattern that is depicted in this figure. The pattern is generated through multiple levels of gene regulation.



a. Describe the pattern shown in the graph and explain why it makes sense with regard to the timing of histone production.

The levels of histone protein are high during S phase when DNA is being replicated and there is a need for new histones for packaging. Histone production is low during the rest of the cell cycle when the amount of DNA in the cell is constant.

b. Propose basic regulatory mechanisms by which the cell can control histone protein levels in a way that produces the pattern shown in the graph.

There are a variety of possibilities. For example, to increase the protein level at S phase, transcription could be increased, translation could be increased, the transcript could be stabilized, or the protein could be stabilized. To decrease protein levels at the end of S phase, the protein could be degraded, the mRNA could be degraded, or the levels of translation and transcription could be reduced.

3. How might the regulation of gene expression in time and space be important in the process of implanting an embryo during the female reproductive cycle?

In order to establish the reproductive cycle, specific genes must be expressed in the reproductive organs (space) at specific times during the cycle. The embryo is only able to implant under the gene expression pattern (and therefore phenotypic conditions) at one particular time during the cycle.

1.5 CELLULAR INFRASTRUCTURE AND GENE EXPRESSION

1. Compare and contrast the nucleoid and the nucleus.

Both are subcellular regions that contain DNA. The nucleoid, which is not surrounded by a membrane, is where DNA is found in prokaryotes. The membrane-bound nucleus contains the DNA in eukaryotic cells.

2. In addition to the nucleus, many cells contain a wide variety of other compartments. Describe some of the advantages of compartmentalization.

a. Localization of specific biological molecules can facilitate specific biochemical reactions.
b. Co-localization of similar processes also increases efficiency.
c. Separation of transcription from translation allows for RNA quality control and processing to occur before there is a commitment to translation.
d. Translation of proteins can occur in the cytosol (mediated by free ribosomes) or can occur on the ER membrane (mediated by ribosomes associated with the ER – that is, rough ER), sorting proteins to where they will be used.

3. Compare the process by which proteins in bacteria and eukaryotes are made and secreted from cells.

In bacteria, there is no compartmentalization, so secreted proteins are targeted directly to the extracellular space as they are translated. In eukaryotes, the internal membrane compartments allow for translated proteins to be folded correctly and modified prior to trafficking to the cell membrane.

Challenge Questions

4. In a leaf cell, both the production of sugars (photosynthesis) and the breakdown of sugars (cellular respiration) occur. Explain how the cell is capable of managing these two opposing biological processes.

   A plant cell compartmentalizes these processes to keep them from interacting. The chloroplasts carry out photosynthesis while the mitochondria carry out cellular respiration.

5. In bacteria, transcription and translation occur in the same cellular compartment while in eukaryotes, they are separated. Give one advantage for each condition.

   In bacteria, a ribosome can start translating an mRNA as it is being transcribed, increasing the speed of protein synthesis. In eukaryotes, the separation of the two processes provides an opportunity for regulation and quality control. The RNA transcript can be processed and checked prior to leaving the nucleus and encountering a ribosome.

1.6 EXPRESSION OF THE GENOME

1. What is the relationship between ploidy and the genotype and phenotype of an organism?

   Ploidy refers to the number of copies of each chromosome an organism possesses. The organism could be haploid (one copy), diploid (two copies) or polyploid (more than two copies. If an organism is haploid, it has a single copy of a particular gene, which comprises the genotype for that gene and is expressed as the organism's phenotype. If an organism is diploid or polyploid, however, the genotype consists of more than one copy of each gene and the phenotype will be dependent upon the interactions between the products of the different copies.

2. Compare and contrast forward and reverse genetics.

   In forward genetics, the phenotype is observed first and the gene responsible subsequently identified. In reverse genetics, a gene with an unknown function is disrupted and then the phenotype is observed. In both cases, the functions of specific genes are determined.

3. Define the following terms with regard to their impact on human disease.

   a. Somatic cell mutation – *disease will affect the individual organism*
   b. Germline mutation – *disease will affect the offspring of the individual*
   c. Monogenic – *disease state is the consequence of a mutation in a single gene*
   d. Polygenic – *disease state is the consequence of the mutations in multiple genes*

e. Penetrance –*the percentage of individuals with a particular mutation that will develop a disease.*

4. Which of the following terms refers to a heritable change that alters the expression of a gene without altering the DNA sequence of a gene?

   b. Epigenetics

Challenge Questions

5. Figure 1.22 shows an *Arabidopsis* mutant that grows tall due to its inability to respond to inhibition by blue light.

   a. What is the difference between a somatic cell mutation and a germline mutation*?*

      Somatic mutations are in body cells and are not passed to the next generation; they are only passed to new cells of the same organism. Germline mutations are in the sex cells and are passed to the next generation.

   b. How would you determine if the *Arabidopsis* mutation is somatic or germline?

      Self-pollinate the plant and determine if the mutation is passed to the next generation.

   c. What is the difference between a dominant and a recessive mutation?

      The phenotype of a dominant mutation would be observed even in the presence of a wild-type allele. The phenotype of a recessive mutation would be masked in the presence of a wild-type allele.

   d. How would you know if the *Arabidopsis* mutation is dominant or recessive*?*

      If it is a somatic mutation, you can use molecular techniques to determine if the cell contains two mutant alleles or one wild-type and one mutant allele. If the mutation is in the germline, you can cross-pollinate the plant with a wild-type plant and determine if the heterozygous offspring show the wild-type or the mutant phenotype.

6. If a normal zebrafish with a striped pattern on its body (wild type) is crossed with a zebrafish that has a spotted pattern (leopard), all of the offspring are wild type, but the second generation features a small number of leopard spotted offspring. Additionally, a comparison of the sequence of the gene responsible for stripes revealed that the leopard mutant had a premature stop codon in the amino acid sequence. Which of the following terms can be used to categorize and describe this mutation? Explain why you chose each answer.

   a. Dominant - *No, the cross produced all striped.*
   b. Recessive - *Yes, the cross produced all striped, the mutant was masked.*
   c. Insertion - *No, this does not describe the premature stop codon*

d. Deletion - *No, this does not describe the premature stop codon*
e. Null - *Yes, this describes the situation where the mutation creates a non-functioning protein*
f. Missense - *No, this does not describe the premature stop codon*
g. Nonsense - *Yes, this describes the situation where a codon is changed to a stop codon*
h. Silent - *No, this does not describe the premature stop codon*
i. Somatic cell - *No, the mutation is passed to the F2 generation*
j. Germline cell - *Yes, the mutation is passed to the F2 generation*
k. Monogenic - *Yes, the sequence of one gene led to the phenotype*
l. Polygenic - *No, the sequence of one gene led to the phenotype*

7. Based on the following wild type sequence, indicate if each of the mutations should be classified as an insertion, deletion, missense, nonsense or silent.

Wild type:	AUG AUA CUA GAA AAC UGA	MILEN	*Wild type*
a.	AUG AUA UUA GAA AAC UGA	*MILEN*	*Silent*
b.	AUG AUA CUA UAA AAC UGA	*MIL*	*Nonsense*
c.	AUG AUC CUA AAC UGA	*MILN*	*Deletion*
d.	AUG AUA CUA GAA AAA UGA	*MILEK*	*Missense*

8. For each disease state below, give a brief description of the disease and indicate which terms from Question 1.6.3 would apply.

a. Duchenne Muscular Dystrophy.

Disorder in which muscles weaken and muscle tissue is lost. This form has early onset and progresses more quickly than other muscular dystrophies. Monogenic; caused by a defect in the dystrophin gene. Germline mutation; X-linked mutation passed to offspring.

b. Smith-Magenis Syndrome.

Developmental disorder characterized by intellectual disability, delayed speech, distinctive facial features, sleep disturbance, and behavioral problems. Monogenic; caused by the loss of function of RAI1. Both germline and somatic; the genetic change usually occurs during the formation of sex cells (which would make it germline) or in early development of the offspring (which would make it somatic).

c. Metabolic Syndrome.

A condition in which an individual has at least three of the following risk factors for cardiovascular disease: abdominal obesity, high triglyceride levels, low HDL cholesterol, high blood pressure, high fasting blood glucose. Polygenic; appears to be caused by variants of a number of candidate genes. Likely germline: it clusters in families and is passed to the next generation.

d. Melanoma.

Cancer of the melanocytes in the skin. Caused by UV light damage to the DNA in skin cells. Polygenic; it typically requires the accumulation of multiple mutations. Somatic; it results from damage to somatic cells and is not passed to the next generation.

1.7 EVOLUTION OF THE GENOME AND THE TREE OF LIFE

1. What is the relationship between DNA mutation, natural selection, and evolution?

   DNA mutation is the random process that produces variety in a population of individuals. Natural selection is the process by which the environmental conditions create a situation in which one of the random variations is favored for survival. Evolution is the process by which the combination of mutation and natural selection lead to gradual changes in the characteristics of an organism over time.

2. What is a phylogenetic tree and how was the tree in figure 1.28 generated?

   A phylogenetic tree is a depiction of the relatedness of organisms. In figure 1.28 the tree was generated by comparing DNA sequence from the ribosomal DNA of the different organisms.

3. Bacteria and Archaebacteria have been separated into two different domains of life.

   a. Why were they originally put together?

      Their appearances are similar: single celled organisms, simple subcellular localization and not membrane bound compartments.

   b. What recent evidence separated them into two domains?

      Sequencing of DNA revealed that core proteins in archaebacteria had more resemblance to eukaryotic proteins than bacterial proteins.

4. What is a model organism? Give an advantage and a disadvantage to studies of model organisms.

   Organisms that are easy to manipulate in the laboratory, yet still possess many of the features of important agricultural and medically relevant organisms. An advantage is that many processes that cannot be studied in relevant organisms directly (like humans) can be studied in these model organisms. The disadvantage is that, although the model organisms are similar to other organisms, they are not the same. Sometimes processes that are understood in model organisms turn out to be different in other organisms.

Challenge Question

5. In a hypothetical forest, beetles of one species had an exoskeleton color that ranged from white to black. The color was dependent on the amount of black pigment produced by one gene. The amount ranged

from none (white) to 100% (black). All of the beetles were able to find camouflage in the forest and were equally protected from bird predators. One day, a fire burned through the forest and turned the environment black.

a. Explain the mechanisms by which the variety of colored exoskeletons may have been produced and maintained in the population.

The white phenotype may be the result of a non-functioning pigment gene. A middle color may be explained by a heterozygous individual, and black by two functioning alleles. Other variants in color are likely due to mutations in genes that regulate the expression of the black pigment gene. All colors were maintained because the environment provided equal protection for all colors from predators.

b. What natural selection is likely to occur due to the fire?

With the environment turned black, the more lightly colored beetles no longer had protection from being seen and were preyed upon by birds. Only the darkest colored beetles were able to survive and pass on their genes to the next generation.

c. What is the likely outcome of natural selection in the next generation of beetles?

They will all be dark beetles.

d. What would have happened in this scenario if there had been no variation in beetle exoskeleton color?

If they were all dark, there would be no change, but if they were all white, or a light color, they might all be eaten, and the population might not have been able to survive the stress.

e. What is the relationship between this scenario and the development of the diversity of life?

Mutations in similar organisms lead to varying abilities to survive under different environmental stresses, leading to the gradual change in organisms as they adapt to different environment. These changes ultimately lead to the development of new species and the diversity of organisms.