CHAPTER 3: THE BIOLOGICAL BASIS OF LIFE

Chapter Outline

I. Introduction
- A. Genetic discoveries and genetically-based technologies are advancing daily and affect our lives.
- B. Genetics is the study of how genes work and how traits are transmitted from one generation to the next.
  1. Genetics unifies the various subdisciplines of physical anthropology.

II. Cells
- A. Cells are the basic units of life in all organisms.
  1. Some organisms are single-celled and others, called *multicellular* organisms, are composed of billions of cells.
  2. An adult human body may be composed of as many as a trillion cells, all functioning in complex ways that ultimately promote the survival of the individual.
  3. Bacteria and blue-green algae appeared about 3.5 billion years ago.
  4. Eukaryotic cells (found in multi-cellular organisms) appeared about 1.7 billion years ago.
     a. The cells are a three-dimensional structure composed of carbohydrates, lipids, nucleic acids, and **proteins**.
        (i) Substructures called *organelles*, include the **nucleus** surrounded by the *nuclear membrane*.
            (a) Inside are two kinds of **molecules,** which contain genetic information in the form of **DNA (deoxyribonucleic acid)** and **RNA (ribonucleic acid**.)
        (ii) The **cytoplasm** surrounds the nucleus and contains various organelles involved in cell and organ function through **protein synthesis**. Among these organelles are the **mitochondria** and **ribosomes**.
            (a) The mitochondria function in energy production and have their own DNA **mitochondrial DNA (mtDNA).**
  5. There are two cell types.
     a. **Somatic cells** are the cellular components of body tissues.
     b. **Gametes** are sex cells: either sperm or ova.
        (i) Two gametes fuse to form a **zygote**.

III. From DNA to Protein
- A. DNA is the basis of life and directs all cellular activities.
  1. The chemical and physical properties of DNA were discovered in 1953 by Crick and Watson.
  2. The DNA molecule is composed of two complementary chains of smaller units called **nucleotides.**
     a. A single nucleotide is composed of a deoxyribose sugar, a phosphate group, and one of four nitrogenous *bases*.
        (i) The bases are *adenine, guanine, thymine, and cytosine* (A, G, T, C).
        (ii) The double helix forms because adenine bonds to thymine and guanine bonds to cytosine.
        (iii) This complementary base bonding is the key to DNA's ability to **replicate** itself.
- B. DNA replication is key to growth and healing of injured tissue in organisms and occurs before the cell divides.
  1. Initially, **enzymes** break the bonds between the two DNA strands.
  2. The exposed bases attract unattached **complementary** DNA nucleotides.

3. The two parental nucleotide chains serve as models for the growing replicated strands.
    a. Thus, each new DNA molecule consists of one original nucleotide chain joined to one new nucleotide chain.

C. One of the most important activities of DNA is to direct **protein synthesis** within cells.
1. Proteins are complex, three-dimensional molecules with the ability to bind to other molecules.
    a. The protein **hemoglobin**, found in red blood cells, is able to transport oxygen through the body because of its ability to bind to oxygen.
2. Some proteins are structural while others (such as enzymes and **hormones**) are functional.
    a. Enzymes regulate chemical reactions.
    b. Specialized cells produce hormones, which target tissues and have specific effects.
3. Proteins are composed of **amino acids**.
    a. There are 20 amino acids; 12 of these are produced within cells.
    b. A protein's function is determined by its sequence of amino acids.
        (i) The sequence of DNA bases taken three at a time (a *triplet*) ultimately specifies which amino acids are to be used to synthesize a protein.
4. Protein synthesis occurs at the ribosomes.
    a. The first step is called *transcription.* This starts in the nucleus as a complementary strand of **messenger RNA (mRNA)** is produced from the DNA strand.
        (i) mRNA differs from DNA in that it is single-stranded, contains a different type of sugar, and has uracil (U) instead of thymine.
    b. The second step*, translation*, occurs at the ribosomes.
        (i) Here, the mRNA strand is "read" by the ribosomes three bases (one **codon**) at a time.
        (ii) This step requires the carrier molecule, **transfer RNA (tRNA).**
        (iii) Each tRNA has the ability to bind to one amino acid.
        (iv) If a DNA base or sequence of bases is changed through **mutation**, some proteins may not be made or may be defective.

IV. What Is a Gene?

A. A **gene** is the sequence of DNA bases responsible for the synthesis of a protein, a portion of a protein, or any functional product (e.g. RNA).
1. New genetic research indicates that we must modify the above definition, since DNA is known to also code for RNA and DNA nucleotides.
2. Sequencing the human **genome** revealed that humans have about 25,000 genes; yet we produce as many as 90,000 proteins.

B. Gene action is complex, since not all segments of DNA are expressed during protein synthesis.
1. **Exons** are DNA segments transcribed and expressed in protein synthesis.
2. **Introns** are **noncoding DNA** segments transcribed but deleted before transcription.

V. Regulatory Genes

A. **Regulatory genes** produce proteins that influence the activity of other genes.
    a. **Homeobox genes** are an evolutionarily ancient group of regulatory genes that directs the development of the overall body plan and the segmentation of body tissues.
        (i) Homeobox genes have been maintained conservatively much throughout evolutionary history.
        (ii) One type of homeobox genes are Hox genes, important to the development of the spinal and thoracic regions.

VI. Cell Division

A. **Cell division** produces new cells.

B. At the beginning of cell division DNA becomes tightly coiled and is visible as a set of discrete structure, or **chromosomes.**
   1. Chromosomes are composed of DNA and protein and each species has a specific number of chromosomes: humans have 46.
      a. There are two types of chromosomes:
         (i) **Autosomes** carry genetic information that governs all physical characteristics except primary sex determination.
         (ii) **Sex chromosomes** determine sex determination:
            (a) Female mammals normally have two X chromosomes, and males normally have one X and one Y chromosome.
   2. **Mitosis** is cell division in somatic cells.
      a. Human somatic cells contain 46 double-stranded chromosomes in the early stages of mitosis.
      b. Chromosomes line up along the center of the cell and are pulled apart at the centromere.
         (i) The result is a genetically identical daughter cell with the full complement of DNA, or 46 chromosomes.
   3. **Meiosis** produces reproductive cells (gametes).
      a. Meiosis has two divisions: a *reduction division* and a second cell division.
         (i) In the first division, pairs of homologous chromosomes line up at the center of the cell. As division proceeds, the double-stranded chromosomes are not pulled apart; rather, the members of pairs migrate to opposite sides of the cell. The result is two cells, each of which contains 23 double-stranded chromosomes. This is also called **recombination** or *crossing over*.
         (ii) In the second division, the 23 double-stranded chromosomes align at the center of the cell and then are pulled apart. This reduction is similar to mitosis.
            (i) The result is four daughter cells, each with 23 single-stranded chromosomes.
      b. **The Evolutionary Significance of Meiosis**
         (i) Meiosis (and sexual reproduction) increases genetic variation in populations.
         (ii) Recombination between partner chromosomes increases the genetic uniqueness of individuals that are not **clones** of one another.
      c. **Problems with Meiosis**
         (i) Failure of homologous chromosomes or chromosome strands to separate during meiosis is termed *nondisjunction*.
            (a) Nondisjunction leads to *trisomy*.
            (b) Trisomy 21 (Down syndrome) occurs when there are three copies of chromosome 21 present in the individual.
            (c) This occurs in about 1/1,000 live births.
         (ii) Nondisjunction may also occur in sex chromosomes, causing sterility, some mental impairment, and other problems.

VII. New Frontiers

A. The discovery of DNA's structure and function has revolutionized biology.
   1. The **polymerase chain reaction (PCR)** technique was developed in 1986 and is used to analyze from small segments of DNA.
      a. With PCR, very small samples of DNA can be examined for the patterns of repeated DNA sequences unique to each individual. This process is called *DNA fingerprinting* and is in forensic science and medicine.
   2. *Recombinant DNA technology* is used to transport genes from one species into another.
      a. Dolly, the sheep, was cloned in 1997. She was euthanized in February 2003 at the age of six years due to health problems she developed.

3. The single most important advance in genetics has been the progress made by the **Human Genome Project (HGP).**
    a. The HGP begun in 1990, with attempts to sequence the entire human genome**.** In 2003 the project was successfully completed.
    b. As of now, the genomes of hundreds of species have been sequenced including mice, chimpanzees, and rhesus macaques.
    c. In May, 2010 the Neandertal genome was sequenced
    d. Scientists have created a functional, synthetic bacterial genome.

Key Terms and Concepts

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Zygote, p. 51

Lecture Suggestions

1. Discuss the importance of genetics and its application to many areas of our lives such as health, reproduction, and food production. Consider the ways that health services (and insurance) are changing to accommodate advances in genetics. Discuss with students the ethics of genetics information.
2. Elaborate on cell function and the specialization of cells. Point out that although all cells carry the same DNA, much of the DNA is "switched off" during fetal development. What new frontiers might this afford us in the future?
3. Elaborate on the universal nature of the genetic code to emphasize the concept of biological continuity. Reinforce the fact that chimpanzees and humans share about 98 percent of their DNA.
4. Provide examples of other autosomal trisomies, such as trisomy 13 (Patau syndrome), and trisomy 18 (Edwards syndrome). Present these as case studies in the class.

Internet Exercises

1. Watson and Crick's original 1953 article, *A Structure for Deoxyribose Nucleic Acid*, can be found at http://www.nature.com/nature/dna50/watsoncrick.pdf. Read the article and list the most important points that are made by the authors.
2. An interesting website on the human genome and cells is located at: https://unlockinglifescode.org/learn/the-animated-genome. There are short animated introductory clips explaining DNA and also cell structure that may be useful in class, especially with beginning level students.
3. For a review of many of the concepts presented in the chapter, see the video clip "From Cell to DNA" at http://sciencenetlinks.com/tools/from-cell-to-dna/.
4. Read, *A Draft Sequence of the Neandertal Genome*, Richard Green et al., 2010, http://www.sciencemag.org/content/328/5979/710.full.

Multiple Choice Questions

1. Cells:
   a. are the basic units of life.
   b. usually do not have DNA.
   c. only have a nucleus and no cytoplasm.
   d. are only inherited from one parent.
   e. originated on earth approximately 5 million years ago.

   ANS: a
   REF: Cells

2. Basic units of the DNA molecule composed of a sugar, phosphate, and one of four DNA bases is called a(n):
   a. protein.
   b. enzyme.
   c. intron.
   d. chromosome.
   e. nucleotide.

ANS: e
REF: From DNA to Protein

3. Somatic cells are *not*:
    a. one type of eukaryotic cell.
    b. also known as gametes.
    c. the cellular components of tissue.
    d. basically all the cells in the body except those involved in reproduction.
    e. those that make up tissues e.g., muscles and the brain.

    ANS: b
    REF: Cells

4. Ribosomes are:
    a. the sex chromosomes.
    b. the gametes.
    c. found only in prokaryotes.
    d. only present when the cell divides.
    e. important to protein synthesis.

    ANS: e
    REF: Cells

5. The two basic types of cells are somatic cells and:
    a. zygotes.
    b. gametes.
    c. autosomes.
    d. polar bodies.
    e. organelles.

    ANS: b
    REF: Cells

6. Gametes:
    a. are basic units of the DNA molecule composed of sugar.
    b. are also called zygotes.
    c. transmit genetic information from parent to offspring.
    d. can make copies of all other types of cells.
    e. are important structural components of the body.

    ANS: c
    REF: Cells

7. A zygote:
    a. is formed by the union of two somatic cells.
    b. has only half the full complement of the necessary genetic material.
    c. is part of a nucleotide.
    d. undergoes meiosis.
    e. has the potential to develop into a new individual.

ANS: e
REF: Cells

8. The structure within the cytoplasm that converts energy is called:
   a. prokaryotes.
   b. eukaryotes.
   c. mitochondria.
   d. messenger RNA (mRNA).
   e. transfer RNA (tRNA).

   ANS: c
   REF: Cells

9. All of the following is true of genetics except it:
   a. is required in only a few of the specialty areas of biological anthropology.
   b. unifies the various subdisciplines of biological anthropology.
   c. is the study of how genes work.
   d. is an approach that explains how traits are inherited across generations.
   e. is not a specialty for most physical anthropologists.

   ANS: a
   REF: Introduction

10. Which of the following nitrogenous bases in *not* found in DNA?
   a. Uracil
   b. Guanine
   c. Thymine
   d. Adenine
   e. Cytosine

   ANS: a
   REF: From DNA to Protein

11. The DNA base adenine always pairs with which other DNA base?
   a. Guanine
   b. Thymine
   c. Cytosine
   d. Uracil
   e. Mitochondria

   ANS: b
   REF: From DNA to Protein

12. Enzymes are:
   a. specialized proteins.
   b. reproductive cells.
   c. a semifluid substance in the nucleus of the cell.
   d. always produced outside the body.
   e. in the formation of a double helix.

   ANS: a

REF: From DNA to Protein

13. Which component of red blood cells is responsible for oxygen transport?
    a. Valine
    b. Hemoglobin
    c. Proline
    d. The cell membrane
    e. The ribosomes

    ANS: b
    REF: From DNA to Protein

14. Which of the following statements concerning RNA is *false*?
    a. It contains the base uracil instead of thymine.
    b. It is single-stranded.
    c. It contains the same sugar as found in DNA.
    d. It is able to pass through the nuclear membrane.
    e. It is involved in the synthesis of proteins.

    ANS: c
    REF: From DNA to Protein

15. Which of the following statements is *false*?
    a. Proteins are composed of amino acids.
    b. The first step in protein synthesis is translation.
    c. The number and sequence of amino acids determines protein function.
    d. Proteins are manufactured by the ribosomes.
    e. The sequence of amino acids in a protein is ultimately determined by the sequence of DNA bases.

    ANS: b
    REF: From DNA to Protein

16. In protein synthesis, the process called transcription is which of the following?
    a. Manufacture of tRNA
    b. Assembly of polypeptide chains
    c. Formation of a mRNA molecule
    d. Production of amino acids
    e. Manufacture of ribosomal RNA

    ANS: c
    REF: From DNA to Protein

17. What do we call the complete sequence of DNA bases that specifies the order of amino acids in an entire protein or portion of protein, or any functional product?
    a. Helix
    b. Codon
    c. Polypeptide
    d. Amino acid
    e. Gene

ANS: e
REF: What Is a Gene?

18. What is the name for DNA segments transcribed into mRNA and coded for specific amino acids?
    a. Exons
    b. Codons
    c. Mutons
    d. Alleles
    e. Proteins

    ANS: a
    REF: What Is a Gene?

19. The two strands of a chromosome are joined at a constricted area called the:
    a. autosome.
    b. ribosome.
    c. centromere.
    d. nucleotide.
    e. cytoplasm.

    ANS**:** c
    REF: Cell Division

20. Chromosomes are:
    a. made up of DNA and proteins.
    b. visible during all stages of cell division.
    c. composed only of mRNA.
    d. indiscrete structures.
    e. occur singularly.

    ANS: a
    REF: Cell Division

21. Homeobox genes are associated with all of the following except:
    a. they interact with other types of genes to determine characteristics.
    b. they are a type of regulatory gene.
    c. there are several different kinds of homeobox genes.
    d. they are highly conserved and maintained over evolutionary history.
    e. they vary greatly from species to species.

    ANS**:** e
    REF: Regulatory Genes

22. Autosomes:
    a. happen only in cases where a genetic deficiency occurs.
    b. carry genetic information that determine the individual's sex.
    c. are found within gametes only.
    d. carry genetic information influencing all physical characteristics *except* primary sex determination.
    e. do not carry genetic information.

ANS: d
REF: Cell Division

23. How many chromosomes occur in a normal human somatic cell?
    a. 44
    b. 48
    c. 46
    d. 53
    e. 23

    ANS: c
    REF: Cell Division

24. How many chromosome *pairs* occur in a normal human somatic cell?
    a. 24
    b. 23
    c. 26
    d. 25
    e. 46

    ANS: b
    REF: Cell Division

25. What are the X and Y chromosomes called?
    a. Autosomes
    b. Gametes
    c. Centromeres
    d. Sex chromosomes
    e. Karyotypes

    ANS: d
    REF: Cell Division

26. The Y chromosome:
    a. is found in both sexes; males have two, and females have one.
    b. influences numerous characteristics in addition to sex determination.
    c. can be inherited from either parent.
    d. carries a gene that causes a fetus to develop as male.
    e. causes a fetus to develop as female if two are present.

    ANS**:** d
    REF: Cell Division

27. Which of the following statements is *true* of mitosis?
    a. The process requires only one cell division to be complete.
    b. There are two cell divisions before the process is complete.
    c. It results in gamete formation.
    d. Crossing-over occurs during mitosis between homologous chromosomes.
    e. Homologous chromosomes come together as pairs during mitosis.

    ANS**:** a

REF: Cell Division

28. After mitosis, daughter cells contain the same amount of DNA as in the original cell. What is this due to?
    a. Protein synthesis
    b. Recombination
    c. Pairing of homologous chromosomes
    d. Meiosis
    e. DNA replication

    ANS: e
    REF: Cell Division

29. Meiosis:
    a. is the cell division process in somatic cells.
    b. replaces cells during growth and development.
    c. permits healing of injured tissue.
    d. is the cell division in specialized cells in ovaries and testes.
    e. involves two divisions and results in six daughter cells.

    ANS: d
    REF: Cell Division

30. Which of the following statements is *false* regarding the process of meiosis?
    a. Meiosis produces gametes.
    b. Meiosis produces daughter cells with half the original amount of DNA found in the original cell.
    c. There are two cell divisions.
    d. Meiosis produces daughter cells with the same amount of DNA found in the original cell.
    e. After recombination, each chromosome contains some new genetic combinations.

    ANS: d
    REF: Cell Division

31. Hox genes are primarily associated with determining the characteristics of what part of the body?
    a. Heart (circulatory system)
    b. Spine (vertebrae)
    c. Limbic system
    d. Endocrine system
    e. Brain

    ANS: b
    REF: Regulatory Genes

32. Which of the following statements is *false*?
    a. Nondisjunction occurs when homologous chromosomes fail to separate.
    b. Nondisjunction occurs when strands of the same chromosome fail to separate.
    c. Nondisjunction can result in a daughter cell with an extra chromosome.
    d. Nondisjunction can result in a daughter cell completely lacking a chromosome.
    e. Nondisjunction occurs only in mitosis.

ANS: e
REF: Cell Division

33. Which of the following is incorrect? Trisomy 21:
    a. is only one of several examples of an abnormal number of autosomes.
    b. is caused by nondisjunction.
    c. is caused by having three copies of chromosome 21.
    d. occurs in 1 out of 10,000 births.
    e. is associated with paralysis of limbs.

    ANS: e
    REF: Cell Division

34. Scientists use _____ to produce many copies of small DNA fragments, such as those obtained at crime scenes or from fossils.
    a. transcription
    b. polymerase chain reactions
    c. nondisjunction
    d. trisomies
    e. random assortment of alleles

    ANS: b
    REF: New Frontiers

35. What was a major goal of the Human Genome Project?
    a. Facilitate human cloning
    b. Map the chromosomes of every human on the planet
    c. Sequence the entire human genome
    d. Trace evolutionary relationships among primates
    e. Prevent overpopulation

    ANS: c
    REF: New Frontiers

True/False Questions

1. A eukaryotic cell is composed of carbohydrates, lipids, and proteins but lacks nucleic acids.

    ANS: False
    REF: Cells

2. Mitochondrial DNA has the same molecular structure and function as nuclear DNA found in the nucleus.

    ANS**:** False
    REF: Cells

3. The discovery of the structure of DNA dates back to the late 1700s.

    ANS**:** False
    REF: From DNA to Proteins

4. The structure of DNA can be described as a triple helix.

   ANS**:** False
   REF: From DNA to Proteins

5. A triplet is a series of three mRNA bases.

   ANS**:** True
   REF: From DNA to Protein

6. Transfer RNA forms a copy of the DNA molecule during translation.

   ANS**:** False
   REF: From DNA to Protein

7. The process of translation during protein synthesis occurs at the ribosomes.

   ANS**:** True
   REF: From DNA to Protein

8. Regulatory genes produce enzymes and other proteins that either switch on or turn off other segments of DNA.

   ANS**:** True
   REF: Regulatory Genes

9. Meiosis occurs only in ovaries.

   ANS**:** False
   REF: Cell Division

10. The result of nondisjunction is that none of the daughter cells will receive any chromosomes.

    ANS**:** False
    REF: Cell Division

11. Nondisjunction can occur in the autosomes but never occurs in the sex chromosomes.

    ANS**:** False
    REF: Cell Division

12. The Human Genome Project was successfully completed in 1952.

    ANS**:** False
    REF: New Frontiers

Short Answer Questions

1. Describe the structure of the DNA molecule in as much detail as you can.

ANS: It is a double-stranded molecule held together by a series of four matching bases.
REF: Cells

2. What is a regulatory gene?

   ANS: It is genes that influence the activity of other genes. They direct embryonic development and are involved in physiological processes throughout life.
   REF: Regulatory Genes

3. What are the two steps in protein synthesis?

   ANS: The two steps are transcription and translation (or decoding).
   REF: From DNA to Protein

4. Compare and contrast the processes and end products of mitosis and meiosis.

   ANS: In mitosis there is a simple division that produces two daughter cells, each of which contains 46 chromosomes. In meiosis there are two divisions that result in four cells, each with only half the original number of chromosomes.
   REF: Cell Division

5. What is the evolutionary significance of meiosis?

   ANS: It increases genetic variation in populations and prevents cloning.
   REF: Cell Division

6. What causes nondisjunction? Give one example of nondisjunction.

   ANS: Nondisjunction occurs when chromosomes or strands do not separate during either of the two divisions. One of the daughter cells gets two copies of the affected chromosome and the other gets none. Trisomy 21 is one of the best-studied examples of nondisjunction.
   REF: Cell Division

7. What is polymerase chain reaction and why is it important in genetics?

   ANS: PCR is a method of producing thousands of copies of a DNA sample. This allows scientists many examples of DNA to analyze and to use for experiments.
   REF: New Frontiers

8. Give two examples of how the field of genetics has revolutionized biological science.

   ANS: Some examples are development of polymerase chain reaction, the Human Genome Project, and sequencing the Neandertal genome.
   REF: New Frontiers

Essay Questions

1. Humans and chimpanzees share about 98 percent of their DNA. What might be the role of regulatory genes in producing the anatomical differences between these two lineages?

   ANS: Will vary

REF: Regulatory Genes

2. Discuss whether it is possible for a human to have the following combinations of sex chromosomes: XYY; XO (only one X and no Y); XXX.

   ANS: Will vary
   REF: Cell Division

3. The definition of gene is currently the subject of some debate. What is the central focus of the debate and what is the reason for the conflicting meanings?

   ANS: Will vary
   REF: What Is a Gene?

4. The progress made in genetics by the Human Genome Project is significant. What was the goal of the project and what is the potential for anthropologists, given that the genomes of other species are being studied?

   ANS: Will vary
   Ref: New Frontiers