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UNIT 7

Cell Division, Genetics and Molecular Biology

Teaching Unit 7: Cell Division, Genetics, and Molecular Biology

(40% percent of the course time; approximately 50 hours)

Student Textbook pages 544-671

Curriculum Fit (See the Curriculum Correlation for Full Listing)

Background: This unit builds on concepts from *Science 9*, Biological Diversity, as well as Unit 2: Ecosystems and Population Change, from *Biology 20*.

General Outcomes

- describe the processes of mitosis and meiosis
- explain the basic rules and processes associated with the transmission of genetic characteristics
- explain classical genetics at the molecular level

Contents

Content Summary

Unit 7: Cell Division, Genetics, and Molecular Biology gives students an understanding of how organisms pass characteristics from one generation to the next and how information about those characteristics is stored in a cell. Unit 7 also examines current trends in related research in genetics.

Chapter 16: Cellular Reproduction begins with a study of cell division—the growth process of many multicellular organisms. In Section 16.1, students examine the process of cellular reproduction and its significance. They describe the general stages of the cell cycle and how genetic material is organized within eukaryotic cells. Students define and explain the significance of chromosome number in somatic (body) cells. In Investigation 16.A, the information is reinforced as students prepare and interpret a model of a human karyotype.

In Section 16.2, students identify the phases of mitosis and their significance. They assess the similarities and differences between mitosis in plant cells and mitosis in animal cells and calculate the duration of individual phases of the cell cycle in Investigation 16.B. To stress the importance of understanding the details of cell division, including the regulation of the process, the mechanics of cancer—rapid, uncontrolled cell division—are introduced.

In Section 16.3, students explore the events of meiosis in detail, including designing a model to compare meiosis and mitosis in Investigation 16.C. They then examine the processes of spermatogenesis and oogenesis, and describe and compare the structure of egg and sperm cells. Finally, students compare the formation of fraternal and identical twins.

In Section 16.4, students describe the diversity of reproductive strategies among living organisms and evaluate the advantages and disadvantages of sexual and asexual reproduction. In Thought Lab 16.2, students research and present information comparing reproductive strategies and assess how research on plant and animal reproduction has affected the development of new reproductive technologies.

Chapter 17 examines the patterns and processes of inheritance. Students will learn how to use tools such as the Punnett square and a pedigree chart to solve problems involving monohybrid and dihybrid crosses, non-dominance, codominance, and multiple alleles. They will also learn how to map genes based on phenotypic data and gain an understanding of the importance of crossing over and recombination in maintaining the diversity of the genes in a population.

Section 17.1: Laying Foundations: Peas, Patterns, and Probabilities introduces the basic principles of Mendelian genetics, including the modification of Mendel's concepts as new knowledge of the structure and movement of chromosomes in meiosis has been related to patterns of inheritance. The Law of Segregation and the Law of Independent Assortment are presented in this section. Seven practice problems are provided to help students understand the concepts, and Investigation 17.A: Testing the Law of Segregation will help students demonstrate the inheritance of a trait, as well as use a Punnett square to interpret the patterns and trends in the data.

In Section 17.2: Extending Mendel's Laws: More Patterns and Probabilities, Mendel's laws are extended by investigating topics such as sex-linked chromosomes, incomplete dominance, and polygenic inheritance. Students learn how genes are arranged on chromosomes and that the probability of recombination of linked genes increases with the map distance between these genes. Students will be able to explain the inheritance patterns for genes on the same chromosome. They will also analyze crossing over data and create a chromosome map for genes on a single chromosome, describe the inheritance patterns for sex-linked genes, and build on the basic concepts of individual genes and complete dominance. They will compare ratios and probabilities of genotypes and phenotypes for multiple alleles and for polygenic traits. There are six more practice problems in this section dealing with blood types, phenotypes, and genotypes. Investigation 17.B: Environmental Influences on Gene Expression guides students in designing and performing an experiment to investigate the influence of environmental variables on the expression of genetic information in an individual.

Finally, in Section 17.3: Genetics and Society, students describe ways in which plant and animal breeding programs make use of genetic research. Students draw and interpret pedigree charts that show the inheritance of single autosomal-dominant, sex-linked-recessive, and autosomal-recessive traits in humans. They design and collaborate on a plan to investigate the inheritance of human traits and assess the role of genetic counselling and technology in issues that involve

society. Students evaluate some of the social, ethical, and economic considerations that are involved in the application of genetic research, specifically at how genetic screening and diagnosis can determine whether an individual carries genes for a particular genetic condition.

Chapter 18: Molecular Genetics looks at the structure and function of DNA and is exciting not only for its science and history, but also for the potential applications that are still on the forefront of science.

The chapter begins by tracing the history of the search for an understanding of structures and the genetic code and allows students to practice some of the techniques in practice problems. In Section 18.1: DNA Structure and Replication, students will summarize the events and experiments that led to the discovery of the structure of DNA and explain how the interaction between DNA and proteins results in the accurate replication of genetic information. In addition to a thought lab on DNA deductions, students design and construct models to simulate the structure and replication of DNA in Investigation 18.A.

The encoding of genetic information in DNA molecules is the subject of Section 18.2: Protein Synthesis and Gene Expression. Since coded information is of no value until it is interpreted, students will find out how the information in DNA is converted into the final product—proteins. It is the proteins that do the work of the cell. Students will learn how the information is transcribed onto a molecule (mRNA) which, in turn, is transported from the nucleus to the cytoplasm where protein synthesis occurs. Then they will analyze the machinery that is required to translate the RNA nucleotide sequence into a protein. Finally, students design and perform a simulation to reinforce their understanding of the steps in the synthesis of a protein in Investigation 18.B.

Section 18.3: Mutations and Genetic Recombination explains some of the causes and effects of DNA mutations. Students will be able to describe how random changes in nucleotide sequences provide sources of both disease and genetic variability and how nucleotide sequences provide evidence that different species of organisms are related. They will also design and perform a simulation to illustrate the use of restriction enzymes and ligases to create recombinant DNA.

Section 18.4 focusses on the social and ethical issues concerning the gathering and management of genetic information. Students will be able to explain how the insertion of new DNA sequences into cells can transform organisms. They will then consider some of the social, environmental, and ethical issues associated with genetic technologies.

Activities and Related Skills

Activity	Target Skills
Chapter 16: Cellular Respiration	
Launch Lab: Cell Division, p. 549	■ Predicting how new, genetically identical cells are produced
Investigation 16.A: Modelling a Karyotype, p. 554	■ Preparing and interpreting models of a human karyotype
Investigation 16.B: Observing the Cell Cycle in Plant and Animal Cells, pp. 559-560	■ Identifying the stages of the cell cycle in plant and animal cells ■ Calculating the duration of each stage of the cell cycle in a plant or animal cell ■ Analyzing the similarities and differences of cell division in plant and animal cells
Thought Lab 16.1: Nondisjunction Syndromes, p. 567	■ Working co-operatively for a presentation of nondisjunction syndromes
Investigation 16.C: Modelling to Compare Meiosis and Mitosis, p. 568	■ Designing a model to simulate the behaviour of chromosomes during mitosis and meiosis ■ Comparing mitosis and meiosis
Thought Lab 16.2: Comparing Reproductive Strategies, p. 579	■ Researching reproductive strategies in a variety of organisms ■ Presenting research results in a suitable form (such as a chart, table, or diagrams)
Chapter 17: Patterns and Processes in Inheritance	
Launch Lab: Coin Toss, p. 585	■ Predicting results based on a hypothesis
Investigation 17.A: Testing the Law of Segregation, p. 592-593	■ Performing an experiment to demonstrate inheritance of a trait that is controlled by a single pair of genes ■ Using a Punnett square to interpret patterns and trends in data

Activity	Target Skills
Thought Lab 17.1: Mapping Chromosomes, p. 602	■ Analyzing crossover data to create a chromosome map
Investigation 17.B: Environmental Influences on Gene Expression, p. 608	■ Designing and performing an experiment to demonstrate a causal relationship between an environmental factor and the expression of genetic information in plants
Thought Lab 17.2: Creating a Pedigree, p. 615	■ Designing a plan to collect data in order to demonstrate human inheritance ■ Drawing and interpreting pedigree charts from human inheritance patterns
Thought Lab 17.3: Analyzing Pedigrees, p. 617	■ Drawing and interpreting pedigree charts from human inheritance patterns
Chapter 18: Molecular Genetics	
Launch Lab: DNA Extraction, p. 623	■ Observing DNA with the unaided eye
Thought Lab 18.1: DNA Deductions, p. 629	■ Constructing a model of a portion of a DNA molecule ■ Analyzing data and applying a conceptual model to infer the structure of a DNA molecule
Investigation 18.A: Modelling DNA Structure and Replication, p. 634	■ Constructing a model of DNA to demonstrate its structure and replication ■ Working cooperatively with team members to construct and assess a model
Thought Lab 18.2: Transcription in Reverse, p. 639	■ Constructing a model of a portion of a DNA molecule ■ Performing a simulation to demonstrate the transcription of a stretch of DNA
Investigation 18.B: Simulating Protein Synthesis, p. 641	■ Performing a simulation to demonstrate the replication of DNA and the transcription and translation of its information ■ Working cooperatively with team members to communicate information and ideas about DNA replication
Thought Lab 18.3: Investigating Cancer Genes, p. 646	■ Analyzing relationships from published data between human activities and genetic changes that lead to inheritable mutations and cancer ■ Working cooperatively to investigate the relationship between human activities and mutations
Thought Lab 18.4: Recreating the First Chimera, p. 649	■ Performing a simulation to demonstrate the use of restriction endonucleases and DNA ligases
Thought Lab 18.5: Reading a DNA Fingerprint, p. 651	■ Analyzing DNA fingerprints

Conceptual Challenges

- Students may be confused to learn that division of somatic cells results in identical daughter cells when the actual cells of an organism differ quite drastically. Introduce the concept of cell differentiation in Chapter 16 to help clarify how somatic cells can differ from one another even though mitosis results in the creation of two daughter cells that are identical to the parent cell in every way.
- Students often have a hard time distinguishing between chromatin, chromatids, and chromosomes. Remind students that the term chromatin refers to the loose, intertwined threads of DNA surrounding histone proteins that occur during interphase of the cell cycle. During S phase of interphase, the DNA replicates and chromosomes are formed at the beginning (prophase) of mitosis and meiosis when the chromatin condenses by successive degrees of coiling. When the chromosomes become visible in mitosis and meiosis, they appear as two identical strands of genetic material held together by a centromere. Each strand is called a chromatid. When the chromatids separate in anaphase, each single chromatid is now referred to as a chromosome. Students may find it especially confusing that single and paired chromatids are both referred to as chromosomes. Use **BLM 16.2.5 (OH) Distinguishing Between Various Forms of Genetic Material** to help clarify the above concepts. You may also want to photocopy this BLM for students to include in their notebooks as a reference.
- Many students will find the concepts of linked genes and chromosome mapping challenging. It is worth spending the extra time on these concepts to help reduce students'

anxiety and confusion. Assign **BLM 17.2.2 (HAND) Chromosome Mapping Worksheet** before introducing Thought Lab 17.1 Chromosome Mapping to increase students' comfort level with these concepts. Thought Lab 17.1 Chromosome Mapping Part B may further confuse students who do not have a solid grasp of linked gene analysis. Assign this portion of the Thought Lab to students who display a firm grasp of genetics.

- Analyzing multiple-allele pedigrees can pose a challenge for many students. Make sure students are confident in working with two-allele pedigrees before moving on to multiple-allele pedigrees in Thought Lab 17.3: Analyzing Pedigrees.
- Some students may find it difficult to visualize the structure of DNA. Photocopy and distribute **BLM 18.1.4 (OH) DNA Nucleotide and Sugar-Phosphate Backbone and BLM 18.1.5 (OH) The Double Helix** for students to keep as a reference in their notebooks. You may also want to consider acquiring a three-dimensional model of DNA for classroom use.
- DNA replication involves many enzymes and other molecules that may be a challenge to remember correctly. Have students create their own reference tables that highlight each enzyme or molecule and the role it plays in DNA replication.
- It may be difficult for some students to understand the procedure involved in the Cohen-Boyer recombinant DNA experiment. Have students read **BLM 18.3.8 (HAND) Cohen-Boyer Experiment** and review the procedure as a class before attempting Thought Lab 18.4: Recreating the First Chimera. Most students will benefit from this clarification of which steps were carried out in this experiment and why.

SUPPORTING DIVERSE STUDENT NEEDS

- Consider pairing or grouping students based on their particular needs, whether for strengthening language skills or consolidating conceptual understanding.
- Students who are having trouble with the vocabulary in this unit can make their own study aids. Because Unit 7 is very visual, a picture-based dictionary may help these students recall the numerous terms introduced in this unit. Have these students write out the definition of a term and draw a picture in colour that will cue their memory for the specific term. Students should then come up with a brief paragraph that incorporates the term and include it with the definition. Students may also benefit from making their own crossword puzzle or word search puzzle, using the terms that are introduced in this unit. Flash cards may also be beneficial.
- Have ESL students develop additional graphic organizers to help them learn the vocabulary associated with this unit. Recommend that these students purchase a biology dictionary from a local bookstore.
- The rich array of interactive resources available through the Internet makes it relatively easy to help students visualize processes such as mitosis, meiosis, transcription, and translation. Web links can be found at **www.albertabiology.ca**. Select Teacher Resources and follow the links to Chapter 16 and 18.
- Create two- or three-page study guides reviewing the ideas covered in each section in the unit. These guides can be of great assistance to students who are struggling with the textbook and lectures. The digests could be in paragraph form, point form, graphic organizer form, or a combination. They might also spotlight key vocabulary and provide essential questions that each section is designed to address. Students could also create these guides themselves, with different students working together in groups, each completing a specific section. Advanced students could be encouraged to make a digital version of these guides using computer slide show presentation software.
- Gifted students may be interested in learning about some of the concepts covered in this unit in more detail. Have a university genetics textbook on hand for such inquiries.

Using the Unit 7 Opener and Unit 7 Preparation Feature

The Unit Opener has been designed to establish a social, technical, and environmental context for the science in the unit. Use the Unit Opener to introduce the general unit topics within that context, and ask the Focussing Questions to guide students' thinking.

- Have the students read the Unit Opener and then write a short paragraph in which they attempt to answer the questions posed in the opener (How can mating behaviour, or the colour of a feather, be programmed into an egg? What natural and human-induced means are there for changing that programming? What are the ramifications of these changes?) based on their current knowledge and ideas. Another option is to discuss these questions together as a class.
- As part of a class discussion, ask students to identify characteristics they have that are passed on in genes (height, blood type, etc.) and those that aren't (scars, loss of a limb, etc.). Why are some characteristic inherited, while others are not?
- Facilitate a class discussion on some of the challenging social and ethical issues associated with genetic research. Challenge students to try to identify these issues or pre-

select issues for discussion before class. Some issues you may want to discuss with your class include genetically modified foods, genetic screening, cloning, transgenic organisms, gene therapy, and management and ownership of genetic information.

The Unit Preparation feature has been included in order to ensure that students are familiar with the science from previous courses that relates specifically to the material they are about to study. Encourage students to take the Unit Prequiz (found at **www.albertabiology.ca,** Online Learning Centre, Student Edition) to gauge their recall, noting that if they are familiar with the background science, their experience with this unit will be much easier. The Unit 7 Preparation feature is a brief review of nucleic acids, the domains of life (Eukarya, Bacteria, and Archaea), and cell structure, focussing on the cell nucleus and ribosomes.

- Use **BLM 16.0.1 (OH) The Domains of Life** and **BLM 16.0.2 (OH) The Cell and Its Organelles** to facilitate a review of the topics covered in the Unit 7 Preparation feature.

UNIT 7: COURSE MATERIALS

Chapter, Section	Item Description	Suggested Quantity	Text Activity
Chapters 16, 17, 18	safety goggles	40 pairs	Investigations: 17.A, 17.B, Ch18 Launch Lab
Chapters 16, 17, 18	nonlatex disposable gloves	40 pairs × 3 investigations	Investigations: 17.A, 17.B, Ch18 Launch Lab
Chapters 16, 17, 18	aprons	40	Investigations: 17.A, 17.B, Ch18 Launch Lab
Chapter 16, Section 16.1	image of the chromosomes in a human body cell blank karyotype form scissors tape	1 per group 1 per group 1 per group 3 rolls	Investigation 16.A: Modelling a Karyotype, p. 554
Chapter 16, Section 16.2	microscope prepared slide of onion root-tip cells prepared slide of whitefish embryo cells	1 per student 1 per student 1 per student	Investigation 16.B: Observing the Cell Cycle in Plant and Animal Cells, pp. 559–560
Chapter 16, Section 16.3	materials as indicated by students' experimental design (e.g., build a clay model, create a computer simulation, perform a play)	as required	Investigation 16.C: Modelling to Compare Meiosis and Mitosis, p. 568
Chapter 17, Chapter Opener	coins	2 per group	Launch Lab: Coin Toss, p. 585
Chapter 17, Section 17.1	*Brassica rapa* seeds and growing systems—order the following seed stocks: – Parental Female (PF) **Non-Purple Stem** (Anthocyaninless: recessive gene blocks the expression of purple, red, or pink pigments) – Monohybrid Genetics Kit #15-8770, Carolina Biological Supply Company (Students explore Mendelian genetics through growing and pollinating F1 hybrid plants to produce F2 seed) – Parental Male (PM) Purple Stem, Hairy (High Anthocyanin: dominant expression of purple pigment in stems) light potting mix plant fertilizer stakes and ties cotton swabs or pipe cleaners labels instructions for growing, tending, pollinating, and harvesting 24-hour fluorescent lights (optional)	10 per group 2 bags 2 bags 40 40 40 10 sets 8	Investigation 17.A: Testing the Law of Segregation, pp. 592–593

Chapter, Section	Item Description	Suggested Quantity	Text Activity
Chapter 17, Section 17.2	seeds (heterozygous seeds, such as green/albino corn seeds or green/albino tobacco seeds, from a scientific supply company petri dishes labels (or marking pen) light source shoe boxes water paper towels 10 mL graduated cylinder other materials as indicated by students' experimental design	20 seeds per group (10 per petri dish) 2 per group 1 per group 1 per group, depending on size of light source 1 per group 2 rolls 1 per group as required	Investigation 17.B: Environmental Influences on Gene Expression, p. 608
Chapter 18, Chapter Opener	mortar and pestle 250 mL beaker 50 mL beakers glass stirring rod cheesecloth 10 mL graduated cylinder small piece of animal tissue 0.9% NaCl solution 10% detergent solution 95% ice-cold ethanol solution meat tenderizing compound (optional)	1 per group 1 per group 2 per group 1 per group 3 pieces per group 1 per group 1 per group 10 mL per group 1.5 mL per group approx. 30 mL per group 1 pinch per group	Launch Lab: DNA Extraction, p. 623
Chapter 18, Section 18.1	materials as indicated by students' experimental design (may include DNA model-building kits, toothpicks, gumdrops, etc.)	as required	Investigation 18.A: Modelling DNA Structure and Replication, p. 634
Chapter 18, Section 18.2	materials as indicated by students' experimental design (may include interactive computer program, props for a play, model kits, or materials for making a model)	as required	Investigation 18.B: Simulating Protein Synthesis, p. 641
Chapter 18, Section 18.3	materials as indicated by students' experimental design (Note: textbook suggests using materials within the classroom)	as required	Thought Lab 18.4: Recreating the First Chimera, p. 649

CHAPTER 16 CELLULAR REPRODUCTION

Curriculum Correlation

General Outcome 1: Students will describe the processes of mitosis and meiosis.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
30–C1.1k define and explain the significance of chromosome number in somatic and sex cells; i.e., haploidy, diploidy and polyploidy	Launch Lab: Cell Division, p. 549 Organization of Genetic Information in a Eukaryotic Cell, p. 551 Chromosome Number, p. 552 Examining Chromosomes: the Karyotype, p. 553 Investigation 16.A: Modelling a Karyotype, p. 554	Launch Lab: Analysis, p. 549 Questions for Comprehension: 5–10, p. 552 11, 12. p. 553 Investigation 16.A: Analysis, Conclusion, p. 554 Section 16.1 Review: 3–7, p. 555 Chapter 16 Review: 2, 5, 10, pp. 582–583 Chapter 16 Test Unit 7 Review: 24, 25, p. 669
30–C1.2k explain, in general terms, the events of the cell cycle, i.e., interphase, chromosomal behaviour in mitosis and cytokinesis	Stages of the Cell Cycle, p. 550 Phases of Mitosis, p. 556 Cytokinesis, p. 558 Mitosis and Cytokinesis in Plant Cells, p. 558 Regulation of the Cell Cycle, p. 560 Investigation 16.B: Observing the Cell Cycle in Plant and Animal Cells, p. 559	Questions for Comprehension: 13, 14, p. 555 15, 16, p. 556 17, 18, p. 558 19, p. 559 Investigation 16.B: Analysis, Conclusion, p. 560 Section 16.1 Review: 3, 6, p. 555 Section 16.2 Review: 1–7, p. 561 Chapter 16 Review: 1, 3, 4, 8, 17, 24, 25, 28, pp. 582–583 Chapter 16 Test
30–C1.3k describe the processes of spermatogenesis and oogenesis and the reduction of chromosomal number in meiosis	The Formation of Gametes, p. 563 Phases of Meiosis, p. 563 Gamete Formation in Animals, p. 568	Questions for Comprehension: 20–22, p. 563 Section 16.3 Review: 1–5, 6 (b-d), 7, 9, 10, p. 572 Chapter 16 Review: 5, 6, 11, 14, 15, 19, pp. 582–583 Chapter 16 Test
30–C1.4k compare the processes of mitosis and meiosis	Investigation 16.C: Modelling to Compare Meiosis and Mitosis, p. 568	Investigation 16.C, p. 568 Chapter 16 Review: 6, 7, 15, pp. 582–583 Chapter 16 Test
30–C1.5k describe the processes of nondisjunction and crossing over and evaluate their significance to organism inheritance and development	Crossing Over, p. 566 Nondisjunction, p. 567 Thought Lab 16.1: Nondisjunction Syndromes, p. 567	Questions for Comprehension: 25, p. 566 26, p. 568 Thought Lab 16.1: Analysis, p. 567 Section 16.3 Review: 6 (a), p. 572 Chapter 16 Review: 13, 20, 26, pp. 582–583 Chapter 16 Test

	Student Textbook	Assessment Options
30–C1.6k compare the formation of fraternal and identical offspring in a single birthing event	Cell Division and the Conception of Twins, p. 570	Questions for Comprehension: 30, p. 571 Section 16.3 Review: 8, p. 572 Chapter 16 Test
30–C1.7k describe the diversity of reproductive strategies by comparing the alternation of generations in a range of organisms; e.g., *protists*, Daphnia, *sea anemone, moss, pine*	Throughout Section 16.4, pp. 573–580 Thought Lab 16.2: Comparing Reproductive Strategies, p. 579	Questions for Comprehension: 31, p. 573 32, 33, p. 574 34–36, p. 575 37, p. 577 Thought Lab 16.2: Analysis, p. 579 Section 16.4 Review: 1–9, p. 580 Chapter 16 Review: 12, 14, 21–23, 27, pp. 582–583 Chapter 16 Test
Outcomes for Science, Technology, and Society (emphasis on social and environmental contexts)		
30–C1.1sts explain that science and technology are developed to meet societal needs and expand human capability by ■ *discussing the role of mitosis and biotechnology in regenerating damaged or missing parts of organisms, e.g., stem cells*	The Reproduction of Somatic Cells, p. 556 Connections—Nature of Science: Regenerating the Sense of Hearing, p. 562	Connections—Nature of Science: 1, 2, p. 562
■ *evaluating how a knowledge of cell division or development of nanotechnology might be applied to the regulation of cancerous growth in plants or animals*		Section 16.2 Review: 5, p. 561 Chapter 16 Review: 17, 26, 28, p. 583 Unit 7 Review: 26, 27, p. 669
■ *discussing and assessing the impact of research in plant and animal reproduction on our understanding of mitosis and meiosis in humans, e.g., cloning, chromosome shortening*	The Reproduction of Somatic Cells, p. 556 Connections—Nature of Science: Regenerating the Sense of Hearing, p. 562	Connections—Nature of Science: 1, 2, p. 562 Chapter 16 Review: 17, 27, p. 583
■ *discussing the types and sources of teratogenic compounds found in the environment and the technological means by which they can be removed or controlled to ensure quality of life for future generations*		Section 16.4 Review: 9, p. 580
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
30–C1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ *defining questions related to mitosis and meiosis, e.g., chromosome shortening, conditions/stimuli for meiosis, aging and mitosis, cytokinesis*	Launch Lab: Cell Division, p. 549	Launch Lab: Analysis, p. 549

	Student Textbook	Assessment Options
Performing and Recording		
30–C1.2s conduct investigations into relationships between and among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ performing a simulation to demonstrate the behavior of chromosomes during mitosis	Investigation 16.C: Modelling to Compare Meiosis and Mitosis, p. 568	Investigation 16.C: p. 568 Chapter 16 Review: 17, p. 583
■ using a microscope and prepared slides of onion root tip cells to identify the stages of a cell cycle and calculate the duration of each stage	Investigation 16.B: Observing the Cell Cycle in Plant and Animal Cells, p. 559	Investigation 16.B: Analysis, Conclusion, p. 560
■ researching a range of reproductive strategies in organisms and presenting them in the form of charts, tables or diagrams, e.g., *alternation of generation showing sexual and asexual phases such as budding, spore production, binary fission*	Investigation 16.B: Observing the Cell Cycle in Plant and Animal Cells, p. 559 Thought Lab 16.2: Comparing Reproductive Strategies, p. 579	Investigation 16.B: Analysis, Conclusion, p. 560 Thought Lab 16.2: Analysis, p. 579
■ *preparing microscope slides to demonstrate some stages of mitosis and meiosis*	Investigation 16.B: Observing the Cell Cycle in Plant and Animal Cells, p. 559	Investigation 16.B: Analysis, Conclusion, p. 560
Analyzing and Interpreting		
30–C1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ preparing and interpreting models of human karyotypes	Investigation 16.A: Modelling a Karyotype, p. 554	Investigation 16.A: Analysis, Conclusion, p. 554 Section 16.3 Review: p. 572 Unit 7 Review: 25, p. 669
■ *analyzing the similarities and differences of cell division in plants and animals*	Investigation 16.B: Observing the Cell Cycle in Plant and Animal Cells, p. 559 Thought Lab 16.1: Nondisjunction Syndromes, p. 567	Investigation 16.B: Analysis, Conclusion, p. 560 Thought Lab 16.1: Analysis, p. 567 Section 16.4 Review: 5–7, p. 580
Communication and Teamwork		
30–C1.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ *working cooperatively with team members in the preparation of mitosis slides*	Investigation 16.B: Observing the Cell Cycle in Plant and Animal Cells, p. 559	Investigation 16.B: Analysis, Conclusion, p. 560
■ presenting two contrasting reproductive strategies, emphasizing the differences	Thought Lab 16.2: Comparing Reproductive Strategies, p. 579	Thought Lab 16.2: Analysis, p. 579

Chapter 16

Cellular Reproduction

Student Textbook pages 548–583

Chapter Concepts

16.1 The Cell Cycle

- Multicellular organisms grow by adding new cells through the process of cell division.
- The cell cycle is the continuous sequence of growth and division that gives rise to all cells.
- The cells of each species have a characteristic number and arrangement of chromosomes.

16.2 The Reproduction of Somatic Cells

- Mitosis involves a precise sequence of events, which can be grouped into four phases.
- The cell cycle is carefully regulated.

16.3 The Formation of Gametes

- Meiosis involves two nuclear divisions to create haploid gametes from diploid parent cells.
- Human gametes form by the processes of spermatogenesis and oogenesis.
- Meiosis contributes to genetic variation.

16.4 Reproductive Strategies

- Different species have life cycles that include different reproductive strategies.
- Many species are capable of both sexual and asexual reproduction.

Common Misconceptions

- Students frequently believe that DNA is replicated during prophase when the sister chromatids become visible. In reality, DNA replication is completed during interphase, well before mitosis begins.
- One of the most common misconceptions about cell division is that all cells divide. In fact, very few cells divide. Many highly differentiated cells never divide. For example, in humans, nearly all neurons are formed by the age of five or six years. From that time on, if a nerve cell body is destroyed, it is rarely replaced. Even differentiated cells that are replaced do not always divide themselves. For example, mature red blood cells do not have a nucleus; therefore, they cannot divide. Instead, red blood cells are replaced when stem cells in the bone marrow divide and differentiate into mature red blood cells.
- Many students think that cells that are not dividing are "stuck" in the G1 phase. However, in G1, cells are carrying out metabolic activities and rapid growth to prepare for cell division. As result, many cell biologists say that non-dividing cells are in a stage called G0 (G zero) to indicate that the cells are *not preparing* to divide.
- Similarly, students may also believe that a cell is "resting" when it is in interphase. This is not the case. During the first part of interphase, called Gap or Growth 1 (G1), cells are carrying out metabolic activities and rapid growth to prepare for cell division. DNA is replicated during the S phase of the cell cycle. Cells that progress through the S phase then enter the last segment of interphase, called Gap 2 or Growth 2 (G2). During the G2 phase, cells are preparing to undergo cell division, reserving energy and producing proteins and other molecules to create the structures required for this process.
- Some students also tend to think that the phases of mitosis and meiosis are discrete events. Make sure that students recognize that the different phases are identified only to make it more convenient to study. In reality, the phases of meiosis and mitosis are continuous events.
- Meiosis is not a cycle like mitosis. Instead, it is a linear process that results in gamete formation. **BLM 16.3.4 (OH) Comparing Meiosis and Mitosis** may be helpful in clarifying this common misconception and illustrating other differences between these two processes.
- Students may believe that second polar bodies can be formed by the secondary oocyte only. In fact, the first polar body may actually undergo further division, producing a second polar body as well. The term "second," therefore, refers to the fact that these polar bodies are formed after the first polar body has been produced.

Helpful Resources

Books and Journal Articles

- Brookes, R. *Genetics: Analysis and Principles 2nd Edition.* Toronto: McGraw-Hill Higher Education, 2005. ISBN 0072965975
- Lewis, R. *Human Genetics: Concepts and Applications 6th Edition.* Toronto: McGraw-Hill Higher Education, 2005. ISBN 0072951745
- *Cell and Chromosome – An Online Journal*. This journal can be accessed at **http://www.cellandchromosome.com/**.
- *Web focus: Nature Cell Biology*. This online journal can be accessed at **http://www.nature.com/ncb/webfocus/division/index.html**

Web Sites

Web links to information about cellular reproduction can be found at **www.albertabiology.ca**. Go to the Online Learning Centre, and log on to Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities; or to supply answers (ANS) for

assessment or handouts. The BLMs are in digital form, stored on the CD that accompanies this Teacher's Resource or on the web site at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links.

Number (Type)

BLM 16.0.1 (OH) The Domains of Life
BLM 16.0.2 (OH) The Cell and Its Organelles
BLM 16.0.3 (HAND) Launch Lab: Cell Division
BLM 16.0.3A (ANS) Launch Lab: Cell Division Answer Key

BLM 16.1.1 (OH) Surface Area to Volume Ratio
BLM 16.1.2 (HAND) Surface Area to Volume Ratio Worksheet
BLM 16.1.2A (ANS) Surface Area to Volume Ratio Worksheet Answer Key
BLM 16.1.3 (OH) The Levels of Organization of Genetic Material
BLM 16.1.4 (HAND) The Levels of Organization of Genetic Material Worksheet
BLM 16.1.4A (ANS) The Levels of Organization of Genetic Material Worksheet Answer Key
BLM 16.1.5 (OH) Homologous Chromosomes
BLM 16.1.6 (OH) The Cell Cycle
BLM 16.1.7 (OH) Human Karyotype
BLM 16.1.8 (HAND) Chromosome Spread
BLM 16.1.9 (HAND) Blank Karyotype Form
BLM 16.1.10 (HAND) Investigation 16.A: Modelling a Karyotype
BLM 16.1.10A (ANS) Investigation 16.A: Modelling a Karyotype Answer Key

BLM 16.2.1 (OH) The Phases of Mitosis
BLM 16.2.2 (HAND) The Phases of Mitosis Exercise
BLM 16.2.2A (ANS) The Phases of Mitosis Exercise Answer Key
BLM 16.2.3 (OH) Mitosis in Animal Cells
BLM 16.2.4 (OH) Mitosis in Plant Cells
BLM 16.2.5 (OH) Distinguishing Between Various Forms of Genetic Material
BLM 16.2.6 (HAND) Investigation 16.B: Observing the Cell Cycle in Plants and Animals
BLM 16.2.6A (ANS) Investigation 16.B: Observing the Cell Cycle in Plants and Animals Answer Key

BLM 16.3.1 (OH) Fertilization
BLM 16.3.2 (OH) The Phases of Meiosis
BLM 16.3.3 (HAND) The Phases of Meiosis Exercise
BLM 16.3.3A (ANS) The Phases of Meiosis Exercise Answer Key
BLM 16.3.4 (OH) Comparing Meiosis and Mitosis
BLM 16.3.5 (HAND) Comparing Meiosis and Mitosis Worksheet
BLM 16.3.5A (ANS) Comparing Meiosis and Mitosis Worksheet Answer Key
BLM 16.3.6 (OH) Potential Genetic Recombination of Diploid Offspring
BLM 16.3.7 (OH) Crossing Over
BLM 16.3.8 (OH) Nondisjunction
BLM 16.3.9 (HAND) Nondisjunction Worksheet
BLM 16.3.9A (ANS) Nondisjunction Worksheet Answer Key
BLM 16.3.10 (OH) Comparison of Oogenesis and Spermatogenesis
BLM 16.3.11 (HAND) Comparison of Oogenesis and Spermatogenesis Exercise
BLM 16.3.11A (ANS) Comparison of Oogenesis and Spermatogenesis Exercise Answer Key
BLM 16.3.12 (HAND) Thought Lab 16.1: Nondisjunction Syndromes
BLM 16.3.12A (ANS) Thought Lab 16.1: Nondisjunction Syndromes Answer Key
BLM 16.3.13 (HAND) Investigation 16.C: Modelling to Compare Mitosis and Meiosis
BLM 16.3.13A (ANS) Investigation 16.C: Modelling to Compare Mitosis and Meiosis Answer Key

BLM 16.4.1 (OH) Binary Fission in Bacterial Cell
BLM 16.4.2 (OH) The Life Cycle of a Fern
BLM 16.4.3 (OH) The Life Cycle of Moss
BLM 16.4.4 (OH) The Life Cycle of a Conifer
BLM 16.4.5 (OH) The Cnidarian Life Cycle
BLM 16.4.6 (HAND) Create an Organism Exercise
BLM 16.4.7 (HAND) Comparing Life Cycles Exercise
BLM 16.4.7A (ANS) Comparing Life Cycles Exercise Answer Key
BLM 16.4.8 (HAND) Thought Lab 16.2: Comparing Reproductive Strategies
BLM 16.4.8A (ANS) Thought Lab 16.2: Comparing Reproductive Strategies Answer Key

BLM 16.5.1 (HAND) Chapter 16 Test
BLM 16.5.1A (ANS) Chapter 16 Test

Using the Chapter 16 Opener

Student Textbook pages 548-549

Teaching Strategies

- Briefly introduce mitosis and meiosis after reading the chapter opener. Ask students how they think mitosis (cell division in somatic cells that produces the genetically identical antler cells in elk) differs from meiosis (cell division in gonads that ultimately results in elk offspring with a wide variety of genetic characteristics).
- Use the Launch Lab: Cell Division.

Chapter 16 Opener Inset Figure

Student Textbook pages 549

Students will not know the answer to this question at this stage. Instead, the question is meant to encourage speculation on the part of students as to how the image would look different if the cell were dividing to produce sperm or egg cells instead of somatic cells. This microscope image depicts cell division during anaphase of mitosis. During anaphase I of meiosis, the image would look quite similar, except that a pair of sister chromatids are pulled to either pole in this stage of meiosis and only one sister chromatid is pulled to either pole

in mitosis. However, this difference may not be visible in a microscopic image of this magnification. In anaphase II, however, the chromosomes would be dividing into four cells instead of two, which would be visible.

Launch Lab: Cell Division

Student Textbook page 549

Purpose

Students will learn that during cell division, the original or parent cell divides to produce two new daughter cells. Cell division (mitosis) ensures that each daughter cell contains the same genetic information as the parent cell.

Outcomes

30–C1.1k

Time Required

30 minutes (10 minutes for students to read material and 20 minutes to complete the Analysis questions).

Helpful Tips

- Use **BLM 16.0.3 (HAND) Launch Lab: Cell Division** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 16.0.3A (ANS) Launch Lab: Cell Division**.
- Before beginning the launch lab, define the terms used in the lab (parent cell, daughter cell, nuclear membrane, cell membrane, cell wall, and chromosomes) as a class. While some terms may be review to students, others will be new.
- Students may be assigned to do this activity in small groups. Although the answers are on the following pages of the text, this will not negate the learning experience since students need experience in reading for comprehension.
- If you wish to have students perform the activity without referring to the text, you might consider doing this activity as a class discussion. You could ask students to propose mechanisms to ensure that a complete copy of genetic information arrives in each cell during the process of cell division. Students could discuss the effectiveness of the proposed mechanisms. You could use this opportunity to introduce the concept of the spindle fibres as the means by which chromosomes are drawn apart during cell division.

Answers to Analysis Questions

1. The number of chromosomes in each daughter cell is the same as the number of chromosomes in the parent cell.
2. The chromosomes in both daughter cells appear to be identical in size and shape to the chromosomes in the parent cell.
3. Students may begin to recognize that the genetic material (chromosomes) must have been duplicated before cell division took place. Each daughter cell received one copy of each chromosome present in the parent cell.
4. If there are 46 chromosomes in the parent cell, then each daughter cell will have 46 chromosomes.

Assessment Options

- Collect and assess student answers to the Analysis questions or discuss as a class.
- Consider doing this activity as a class discussion rather than assessing it formally.

16.1 The Cell Cycle

Student Textbook pages 550-555

Section Outcomes

Students will:

- examine the process of cell division and its significance
- describe the general stages of the cell cycle
- describe how genetic material is organized within eukaryotic cells
- define and explain the significance of chromosome number in somatic cells
- prepare and interpret a model of a human karyotype

Key Terms

cell cycle
somatic cells
parent cell
daughter cell
DNA
chromosome
histones
chromatin
centromere
homologous chromosomes
autosomes
sex chromosomes
genes
locus
alleles
diploid
haploid
gametes
polyploid
karyotype
interphase
G1 phase
S phase
sister chromatids
G2 phase
mitosis
cytokinesis

Biology Background

- The lengths of the various phases in the cell cycle differ significantly among various types of cells, but the combination of mitosis and cytokinesis is always the shortest phase and G1 is nearly always the longest phase. While some cells (for example, skin cells) divide frequently, others, such as nerve cells, spend most of their life cycle in a phase some scientists refer to as "G0," in which they are not actively dividing.
- Chromosome banding patterns are a result of the stain used to prepare the karyotype, as different stains are taken up preferentially by sections of DNA rich in specific nucleotides (i.e., G-C rich and A-T rich sequences). The most widely used staining technique for chromosome analysis is the Giesma stain, which results in the conventional staining pattern seen in most karyotypes, G-banding. This banding pattern is named for the Giesma dye, but can be produced by other dyes as well. G-banding results in alternating light (euchromatic G-C rich regions) and dark bands (heterochromatic A-T rich regions). This technique is most helpful in identifying structural chromosomal abnormalities. Other common banding techniques include C-banding (specifically stains for heterochromatin, such as in centromeres), Q-banding, which uses a fluorescent stain to show chromosomal rearrangements (banding pattern is similar to G-banding), and R-banding (reverse G-banding pattern; dark regions are euchromatin and light regions are heterochromatin).
- Several web sites have figures of human karyotypes and chromosome spreads that may interest your students. Web links can be found at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links.

Teaching Strategies

- Use **BLM 16.1.1 (OH) Surface Area to Volume Ratio** to review this concept. It was introduced to students in *Science 10* in Alberta, but many may not remember how to calculate this ratio. **BLM 16.1.2 (HAND) Surface Area to Volume Ratio Worksheet** can be assigned to students who are still struggling with this concept.
- **BLM 16.1.3 (OH) The Levels of Organization of Genetic Material** is similar to Figure 16.2 on page 552 of the textbook. Use an overhead teaching tool or photocopy and distribute this BLM for your students to file in their notebooks for future reference.
- To help illustrate the importance of the highly organized arrangement of DNA in cells, organize students into small groups. Bring several long ropes (DNA) and tin cans (histones) to class and challenge students to see which group can get the cans and rope to fit into the smallest space or "nucleus." **BLM 16.1.4 (HAND) The Levels of Organization of Genetic Material Worksheet** can also be used to help reinforce the various levels of organization for students.
- **BLM 16.1.5 (OH) Homologous Chromosomes** and **BLM 16.1.6 (OH) The Cell Cycle** can be used as teaching tools to help illustrate a discussion of these topics. Both BLMs can also be photocopied and distributed to your students for their notebooks. Students can write notes directly on the figures while you are discussing them.
- Figure 16.4 on page 553 introduces students to a normal human karyotype. You may want to bring in other karyotypes from genetic diseases such as Down syndrome and Turner syndrome, where one chromosome is missing or in excess, so that students have a chance to become familiar with these karyotypes before they cover nondisjunction, monosomy, and trisomy in chapter 17.
- **BLM 16.1.7 (OH) Human Karyotype** can be used to either introduce Investigation 16.A: Modelling Human Karyotypes or as a tool to evaluate this investigation. **BLM 16.1.8 (HAND) Chromosome Spread** and **BLM 16.1.9 (HAND) Blank Karyotype Form** provide the images of chromosomes and the blank karyotype form that students need to complete this investigation.

Answers to Questions for Comprehension

Student Textbook page 551

Q1. There is a limit to how large a cell can grow because, as a cell grows, the volume of its cytoplasm increases at a faster rate than the surface area of its plasma membrane. As the volume of the cytoplasm increases, more materials must pass through this membrane. If a cell continues to grow in size, its plasma membrane would eventually be too small to meet its metabolic needs. Thus, a cell must stop growing once it reaches a certain size. New growth must, therefore, come from the addition of new cells.

Q2. The cell cycle is the continuous sequence of growth and division that a cell goes through during its lifetime. By convention, a single cell cycle is defined as the sequence of events from one cell division to the next.

Q3. The following is a summary of the technological advances that lead to the development of new theories about the origin of cells:

- Until the mid-1800s, most scientists accepted the theory of spontaneous generation.
- 1840s: Advances in lens technologies increased the magnification power of microscopes from 270× to 1200×. This advance helped scientists observe cell division and propose an alternative theory of how living cells originate.
- 1855: Virchow became the first scientist to publish the conclusion that new cells arise only from the division of other cells.
- 1879: Flemming used synthetic clothing dye (first produced in the mid-1800s) to stain a specimen of tissue. The stain was picked up by a substance in the nucleus that he called chromatin. Within a few years, Flemming offered the first accurate description of the cell cycle and the process of cell division in animal and plant cells.

Q4. The central feature of the cell cycle is the way that genetic material is duplicated and then passed from the original cell (parent cell) to the new cell (daughter cell).

Student Textbook page 552

Q5. The genetic information of a cell is contained in the DNA of its chromosomes. A chromosome is a length of DNA and its associated proteins. In eukaryotic cells, the chromosomes are found in the nucleus.

Q6. A centromere is a specialized, constricted (pinched-in) region that is found in the centre of a chromosome. It joins pairs of identical chromosomes (chromatids) in a chromosome pair.

Q7. There are 46 chromosomes in the somatic cells of humans.

Q8. Homologous chromosomes carry the same genes—areas of DNA that contain specific genetic information—at the same location; however, they are not identical. Instead they carry different forms (alleles) of the same gene. Homologous chromosomes also have several other characteristics in common, such as their length, centromere location, and banding pattern.

Q9. The X and Y chromosomes are known as the sex chromosomes because they determine the sex of the individual. A human female has two X chromosomes, and a human male has one X chromosome and one Y chromosome.

Q10. A cell that contains pairs of homologous chromosomes is said to be diploid, a cell that contains unpaired chromosomes is said to be haploid, and a cell that contains sets of more than two homologous chromosomes is polyploid.

Student Textbook page 553

Q11. The particular set of chromosomes that an individual possesses is called the individual's karyotype.

Q12. A pair of homologous chromosomes carries the same genes at the same locations (loci) on each chromosome. Each pair of the 22 human chromosomes, and the X and Y chromosome, is distinct from the others because it carries different genes.

Investigation 16.A: Modelling a Karyotype

Student Textbook page 554

Purpose

Students will prepare and analyze a model of a human karyotype.

Outcomes

30–C1.3.s

Advance Preparation

When to Begin	What to Do
2 days before	■ Photocopy **BLM 16.1.7 (OH) Human Karyotype, BLM 16.1.8 (HAND) Chromosome Spread, BLM 16.1.9 (HAND) Blank Karyotype Form**, and **BLM 16.1.10 (HAND) Investigation 16.A: Modelling a Karyotype**. ■ Arrange for a class set of paper, scissors, and tape.

Materials

- image of the chromosomes in a human somatic cell [**BLM 16.1.8 (HAND) Chromosome Spread**]
- blank karyotype [**BLM 16.1.9 (HAND) Blank Karyotype Form**]
- scissors
- tape

Time Required

45 minutes

Helpful Tips

- Use **BLM 16.1.10 (HAND) Investigation 16.A: Modelling a Karyotype** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 16.1.10A (ANS) Investigation 16.A: Modelling a Karyotype**.
- Hand out **BLM 16.1.8 (HAND) Chromosome Spread** and **BLM 16.1.9 (HAND) Blank Karyotype Form**. Remind students to carefully cut out the individual chromosomes from the photographed metaphase spread. If you wish, photocopy **BLM 16.1.7 (OH) Human Karyotype** and hand to students to use as a guide to help them arrange each chromosome on the blank karyotype form.
- Tell students not to tape the chromosomes to the karyotype form or throw away any paper scraps until they have identified each chromosome.
- Use the following key to help students identify the chromosomes:
  - The three largest pairs of chromosomes are placed in Group A. They have centromeres near the middle of the chromosomes.
  - Group B includes two pairs of large chromosomes, which have their centromeres close to one end.
  - Group C includes seven pairs of medium-length chromosomes, plus the X chromosome. Their

centromeres are slightly off-centre. The X chromosomes are about the size of chromosomes 7 and 8 of the C group. Thus a normal female will have 16 C-length chromosomes; a normal male, only 15.
  - Group D has three pairs that are slightly smaller than those in group C, but their centromeres are very close to one end.
  - Group E also has three pairs, but their centromeres are a bit closer to the centre of each chromosome.
  - Group F has two pairs of short chromosomes with centromeres in the middle.
  - Group G has two pairs of the smallest chromosomes, plus the Y chromosome in males, which is about the size and shape of those in the G group. The centromeres of these chromosomes are very close to one end.
- Putting students into teams of two or three will save time. One student can be responsible for cutting out the chromosomes while the others start to arrange them on their blank karyotype form.

Safety Precautions

Ase necessary remind students to handle scissors properly to avoid any accidents.

Answers to Analysis Questions

1. This cell has 46 chromosomes. Therefore the diploid number ($2n$) for this cell is 46, and the haploid number (n) is 23. This is written as $n = 23$.

2. If this were a sperm or an egg cell, there would only be 23 chromosomes present. The chromosome number would be $n = 23$.

3. If the karyotype contains 22 pairs of homologous chromosomes and an X and a Y chromosome, the individual is male. If the karyotype contains 22 pairs of homologous chromosomes and two X chromosomes, the individual is female.

Answer to Conclusion Question

4. It is possible to determine if an individual has a normal number of chromosomes by seeing if there are 22 pairs of homologous chromosomes and either two X chromosomes (female), or an X and a Y chromosome (male). Additional chromosomes to the normal number of 46 would indicate a chromosomal abnormality, as would deletions of part or whole chromosomes.

Assessment Options

- Collect and assess students' answers to the Analysis and Conclusion questions.
- Collect and assess the karyotype forms students created in Procedure Step 4.

Answers to Questions for Comprehension

Student Textbook page 555

Q13. The cell cycle is made up of two main stages: a growth stage (interphase) and a division stage (cell and cytoplasmic division). Interphase includes a series of distinct phases: G1 (Gap 1 or Growth 1), S (synthesis), and G2 (Gap 2 or Growth 2). The division stage consists of mitosis and cytokinesis.

Q14. G1 phase: Rapid growth and metabolic activity occurs.

S phase: The DNA in the chromatin replicates to create a second identical set of DNA.

G2 phase: The cell rebuilds its reserves of energy to prepare for division. As well, the cell manufactures proteins and other molecules to make structures required for division of the nucleus and cell.

Mitosis: The genetic material and the contents of the nucleus are divided into two complete and separate sets.

Cytokinesis: The cytoplasm and the organelles are divided into two separate cells.

Section 16.1 Review Answers

Student Textbook page 555

1. As a seedling grows into a tree, the size of the plant increases. To accommodate this growth, cells must divide, rather than simply grow larger. As a cell grows in size, the volume of its cytoplasm increases at a faster rate than the surface area of its plasma membrane. A cell absorbs nutrients and excretes wastes through its plasma membrane. As the volume of the cytoplasm increases, more materials must pass through this membrane. If a cell continues to grow in size, its plasma membrane becomes too small to meet its metabolic needs. New growth, therefore, must come from the addition of new cells. Another reason cells must divide as a seedling matures is that different cell types are required to meet the structural and metabolic needs of the plant (i.e. the cells that make up bark, leaves, roots, etc. all differ). Cell division is necessary to produce these differentiated cells.

2. As microscopes and their lenses became further developed, greater magnification followed; new synthetic stains that specifically stained the chromatin in the nucleus made it possible to identify the chromatin and observe its behaviour during mitosis.

3.
  - G1 (Gap 1 or Growth 1) phase: The first growth stage in which rapid growth and metabolic activity occurs.
  - S phase: The synthesis phase in which a duplicate set of DNA is produced.
  - G2 (Gap 2 or Growth 2) phase: A second growth phase in which the cell rebuilds its energy reserve and produces the numerous proteins and other substances required for mitosis and cytokinesis.

- Mitosis: The division of the cell nucleus and its genetic material.
- Cytokinesis: The division of the cytoplasm and the organelles into two daughter cells.

4. **(a)** Haploid cells have one set of unpaired chromosomes. Diploid cells have one set of paired homologous chromosomes.

   (b) Chromatin is the diffuse DNA and associated proteins the exits in interphase. A chromosome is the highly coiled and condensed chromatin that is visible during mitosis.

   (c) The XX chromosomes are the homologous chromosomes found in female organisms. The X and Y chromosome are nonhomologous chromosomes found in male organisms.

5. Each chromosome of a homologous pair has: 1. the same length and size, 2. the same banding pattern when stained, and 3. the same genes at the same loci, although alleles differ.
6. The chromatin is replicated during the S (synthesis) phase of the cell cycle to create two identical chromosomes.
7. A human cell with an X and Y chromosome came from a male because the Y chromosome is the human male sex chromosome. The cell is somatic because it has 22 pairs of autosomes. It is diploid because it has 46 chromosomes (22 homologous pairs and an X and Y chromosome).

16.2 The Reproduction of Somatic Cells

Student Textbook pages 556-561

Section Outcomes

Students will:

- identify the phases of mitosis and describe their significance
- assess the similarities and differences between mitosis in plant cells and mitosis in animal cells
- calculate the duration of individual phases of the cell cycle

Key Terms

prophase
centrioles
spindle apparatus
metaphase
anaphase
telophase
cell plate
cancer

Biology Background

- Cell division and apoptosis (preprogrammed cell death) are two opposing processes that keep the number of healthy cells in balance. This balance is critical to life and is normally tightly regulated. Generally speaking, in cancer, either proto-oncogenes (genes promoting cell growth), tumour suppressor genes (genes regulating apoptosis or anti-proliferation factors), or genes that regulate these genes become mutated and fail to regulate these functions. The result is out-of-control cell growth, resulting in a tumour. Tumours resulting from a mutation in tumour suppressor genes tend to a have a poor prognosis, as cell damage instigated by cancer therapy fails to result in the intended apoptosis of the cancer cells. In addition to avoiding programmed cell death, malignant tumours also tend to have an amplified rate of cell division, produce their own growth factors, are able to metastasize (invade nearby tissues), show limited differentiation, have no contact inhibition, and exhibit angiogenesis (the ability to create blood vessels to ensure their own blood supply).

Teaching Strategies

- You may wish to introduce this chapter by discussing cancer, as most students know of someone who has cancer, or who has died as a result of cancer. This may be a sensitive topic for some students. Explain to students that cancer is the result of uncontrolled cell division (mitosis). One out of three North Americans will develop cancer. Of those, one out of four males and one out of three females will die of cancer. Fossil evidence indicates that cancer has been killing plants and animals for millions of years.
- Use **BLM 16.2.1 (OH) The Phases of Mitosis** to help teach the steps of mitosis, and **BLM 16.2.3 (OH) Mitosis in Animal Cells** and **BLM 16.2.4 (OH) Mitosis in Plant Cells** to highlight the differences that occur during mitosis in plant and animal cells. These overhead transparencies can also be converted into digital images, or you may want to photocopy and distribute these BLMs as a handout and allow the students to take notes directly on the figure while you discuss the events that occur during each phase of mitosis.
- **BLM 16.2.2 (HAND) The Phases of Mitosis Exercise** can be assigned to students to provide a review of mitosis or may be given as an in class quiz.
- The Biology File: Try This on page 558 provides an excellent way to get students thinking about why each of the steps that occur in mitosis is essential for the efficient division of cells.
- **BLM 16.2.5 (OH) Distinguishing Between Various Forms of Genetic Material** helps students understand the differences between chromatin, chromatids, and chromosomes, terms that often confuse students. Use this BLM as an overhead as part of a class discussion or photocopy and provide to students as a reference to keep with their notes.
- Check with your local media distribution outlet to see if they have any videos that discuss mitosis. It is usually helpful for students to visualize these events in real time rather than to simply look at the illustrations in a textbook. If possible,

arrange to have a computer, Internet access, and an LCD projector in your room. There are also many web sites that have video and/or animations that deal with mitosis. Having access to such videos will help your students realize that, although these phases are continuous, they are divided into four main phases for convenience, according to the sequence in which they occur. Links to relevant web sites can be found at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links.

- Have students draw or use pipe cleaners to model the events that take place in a cell during mitosis. It is worth the extra effort to reinforce the events that take place in mitosis, as it is important that students have a clear picture of mitosis before discussing meiosis in the next section.

Figure 16.7

Student Textbook page 556

A study of these processes could help individuals who have lost an appendage due to illness or injury. They could also lead to treatment of people who are paralyzed as a result of damage to their spinal cord.

Answers to Questions for Comprehension

Student Textbook page 556

Q15. The processes of mitosis and cytokinesis have three important functions:

- Growth: They enable organisms to grow from a single-celled zygote into a mature organism that may contain hundreds of trillions of cells.
- Maintenance: They produce new cells to replace worn or dead cells.
- Repair: They can regenerate damaged tissues.

Q16. It is important for each daughter cell to receive the correct genetic information; otherwise it might not be able to carry out its specific function. In the absence of precise, exact genetic duplication, one of the daughter cells will receive a flawed, mutant genome that may threaten its ability to survive, or even worse, cause it to grow uncontrollably as a cancer cell.

Biology File: Try This

Student Textbook page 558

Students may decide that the DNA needs to spread out during interphase in order for the cell to carry out its metabolic activities and for the DNA to replicate. The chromatin has to shorten and coil just before cell division in order to ensure that each daughter cell gets one exact pair of homologous chromosomes.

Answers to Questions for Comprehension

Student Textbook page 558

Q17. The four phases of mitosis are prophase, metaphase, anaphase, and telophase.

Q18. The key events that happen to chromosomes in each phase are as follows:

- Prophase—the chromatin condenses into tightly packed chromosomes.
- Metaphase—spindle fibres from opposite poles attach to the centromere of each chromosome; the spindle fibres guide the chromosomes to the equator of the cell.
- Anaphase—each centromere splits apart; the sister chromatids separate and are pulled to opposite poles of the cell as the spindle fibres attached to them shorten.
- Telophase—the chromatids have reached the opposite poles of the cell; the chromatids begin to unwind into the longer and less visible strands of chromatin.

Student Textbook page 559

Q19. The structural differences between plant cells and animal cells lead to some differences in mitosis and cytokinesis:

- Plant cells do not have centrioles, but they do form a spindle apparatus.
- The rigid cell wall of a plant cell is much stronger than the membrane of an animal cell. The cell wall does not furrow and pinch in during cytokinesis. Instead, a membrane called a cell plate forms between the two daughter nuclei. This cell plate extends across the diameter of the cell, and it is then reinforced by the addition of cellulose and proteins to create a new cell wall.

Investigation 16.B: Observing the Cell Cycle in Plants and Animals

Student Textbook pages 559-560

Purpose

Students will identify the stages of the cell cycle in plant and animal cells, calculate the duration of each stage of the cell cycle in a plant or animal cell, and compare cell division in plant and animal cells.

Outcomes

- 30–C1.2s
- 30–C1.3s

Advance Preparation

When to Begin	What to Do
Several weeks before	■ Check that you have sufficient prepared slides of onion root-tip cells and whitefish embryo cells. ■ Book science lab if necessary.
2-3 days before	■ Check that all microscopes are functioning properly.
1 day before	■ Ask students to read the investigation at home the evening before. ■ Photocopy **BLM 16.2.6 (HAND) Investigation 16.B: Observing the Cell Cycle in Plants and Animals**. ■ Photocopy **BLM 16.2.3 (OH) Mitosis in Animal Cells** and **BLM 16.2.4 (OH) Mitosis in Plant Cells**, if using.

Materials
■ imicroscope ■ prepared slide of onion root-tip cells ■ prepared slide of whitefish embryo cells

Time Required

1 hour

Helpful Tips

- Use **BLM 16.2.6 (HAND) Investigation 16.B: Observing the Cell Cycle in Plants and Animals** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 16.2.6A (ANS) Investigation 16.B: Observing the Cell Cycle in Plants and Animals Answer Key**.
- You may also want to photocopy and distribute **BLM 16.2.3 (OH) Mitosis in Animal Cells** and **BLM 16.2.4 (OH) Mitosis in Plant Cells** to your students. These BLMs will provide your students with a comparison of the processes of mitosis in plant and animal cells, providing a useful resource that they can refer to throughout the investigation.
- There are a number of web sites that provide images of both onion root-tip cells and whitefish embryo cells. Project these images on a screen or white board for your students before they start this investigation. This will give them a better idea of what they need to look for when viewing their own slides. Web links related to this investigation can be found at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links.
- If you have a microscope-camera, you could walk your students through the procedure for this investigation.
- Review the proper techniques for handling a microscope and the procedure for viewing slides under the high power objective. These steps are provided in Appendix C Microscopy Review.
- When students are counting the cells in the onion root-tip, have them work in pairs. One partner can observe the slide and call out the phase of each cell, while the other partner records the information in the data chart. Students can then switch roles so the recorder becomes the observer, and vice versa.

Safety Precautions

- Remind students to be sure that the microscope is turned off and their hands are dry when they plug in or disconnect the cord.
- Students should handle the microscope slides with care. Students may break the prepared slides if they do not follow the proper procedure for focussing the microscope. Have the procedures in place for the proper disposal of broken glassware.

Answers to Analysis Questions

1. (a) The size of the cells increased as one moved further away from the root tip.

(b) The cells farther away from the root tip were more rectangular, while the recently divided cells were nearly square.

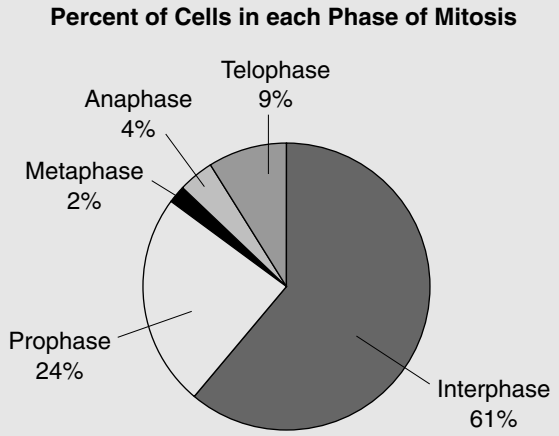
(c) There were fewer dividing cells as one moved further away from the root tip.

2. (a) The whitefish cells were larger than the onion root-tip cells.

(b) The more mature onion root-tip cells were more rectangular, while cells that had recently divided were nearly square. Whitefish cells were more round in shape.

(c) Students likely will describe little or no difference in chromosome arrangements. Some students might make reference to the appearance of the cell plate in the onion cells and the appearance of an indentation ("cleavage furrow") in the whitefish cells during cytokinesis. Some students might be able to observe, and thus may make reference to, centrioles in the whitefish cells. Accept all reasonable answers.

3. The following is an example of a pie graph that students should generate.



4. No, cell division only takes place near the tip of the onion root. Cells closer to the root tip will undergo cell division much more rapidly that cells further away from the growing region of the root.

Answer to Conclusion Question

5.

Phase	Animal Cells	Plant Cells
Interphase	Most of the cell's life is spent in the growth stage, which is called **interphase**. During interphase, the cell carries out its regular metabolic functions and prepares for its next division.	Most of the cell's life is spent in the growth stage, which is called **interphase**. During interphase, the cell carries out its regular metabolic functions and prepares for its next division.
Prophase	During prophase, the chromatin condenses into tightly packed chromosomes. The nuclear membrane breaks down, releasing the chromosomes into the cytoplasm. The nucleolus disappears. One pair of cylindrical organelles, called centrioles, moves apart to opposite poles of the cell. As the centrioles move apart, a network of fibres called the **spindle apparatus** forms between them.	Plant cells do not have centrioles, but they do form a spindle apparatus. Otherwise the events are the same in both plants and animal cells.
Metaphase	During metaphase, spindle fibres from opposite poles attach to the centromere of each chromosome. The spindle fibres attach in such a way that one sister chromatid is linked to one pole, while the other sister chromatid is linked to the opposite pole. The spindle fibres guide the chromosomes to the equator, or centreline, of the cell.	The events are the same in both plant and animal cells.
Anaphase	During anaphase, each centromere splits apart and the sister chromatids separate from one another. The spindle fibres that link the centromeres to the poles of the cell shorten. As these fibres shorten, sister chromatids are pulled to opposite poles. At the same time, other microtubules in the spindle apparatus lengthen and force the poles of the cell away from one another. At the end of anaphase, one complete diploid set of chromosomes has been gathered at each pole of the elongated cell.	The events are the same in both plant and animal cells.
Telophase	Telophase begins when the chromatids have reached the opposite poles of the cell. The chromatids begin to unwind into the longer and less visible strands of chromatin. The spindle fibres break down. A nuclear membrane forms around each new set of chromosomes, and a nucleolus forms within each new nucleus.	The events are the same in both plant and animal cells.

Phase	Animal Cells	Plant Cells
Cytokinesis	Cytokinesis is the division of the cytoplasm to complete the creation of two new daughter cells. During cytokinesis an indentation forms in the cell membrane along the cell equator. This indentation deepens until the cell is pinched in two. The cytoplasm and organelles divide equally between the two halves of the cell. Cytokinesis ends with the separation of the two daughter cells. The daughter cells are now in interphase, and the cycle continues.	The rigid cell wall of a plant cell is much stronger than the membrane of an animal cell. The cell wall does not furrow and pinch in during cytokinesis. Instead, a membrane called a **cell plate** forms between the two daughter nuclei.

Assessment Options

- Have the students write up a formal lab report with answers to Analysis and Conclusion questions to be handed in for marking.
- Use Assessment Checklist 2 Laboratory Report. (See Appendix A.)

Section 16.2 Review Answers

Student Textbook page 561

1. Mitosis governs the growth, repair, and maintenance of human tissues.

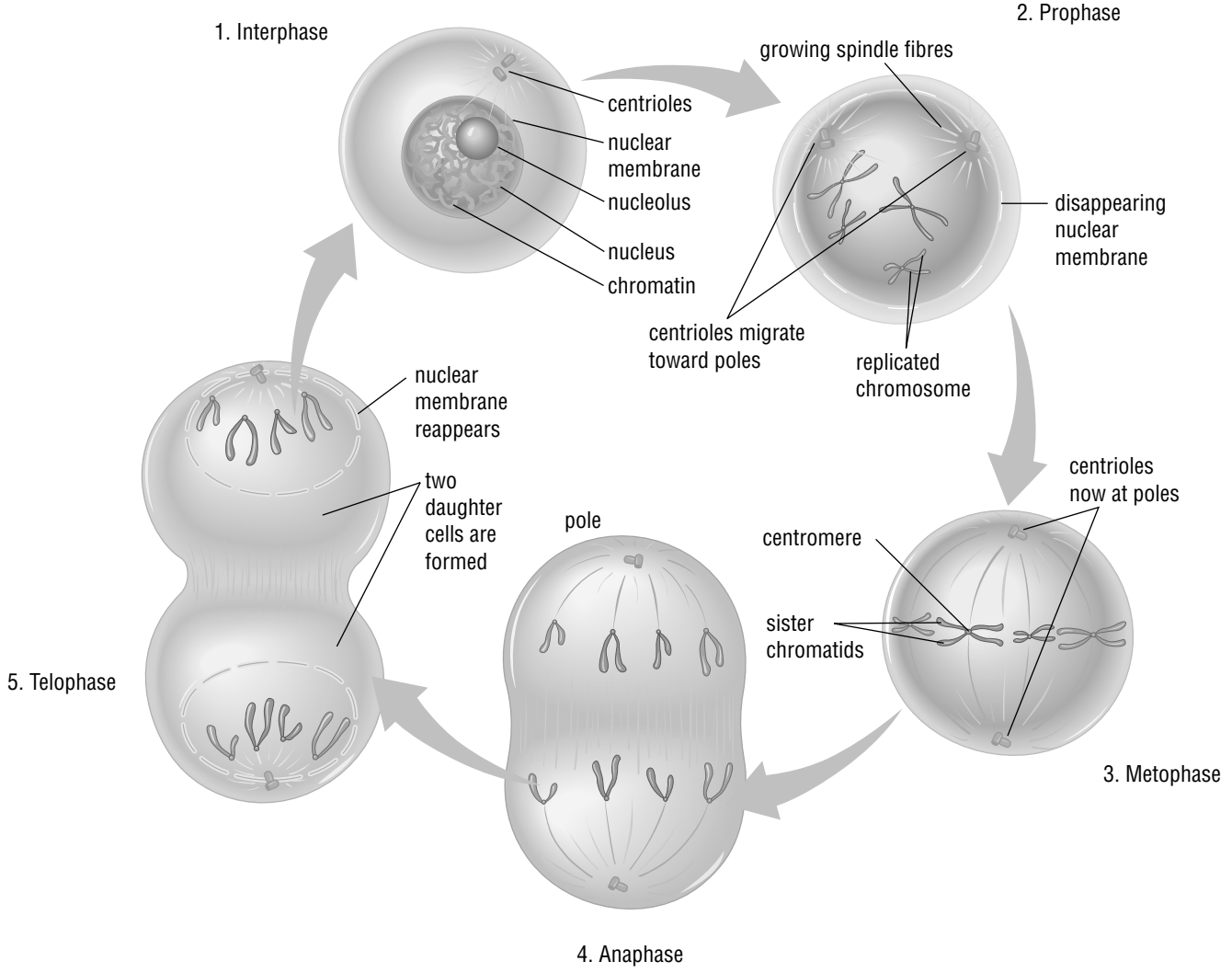
2. (a) Sister chromatids migrate to opposite poles during anaphase.

(b) Chromatin condenses to form chromosomes during prophase.

(c) The nuclear membrane forms during telophase.

(d) The chromosomes align at the cell equator during metaphase.

3. Students' sketches should resemble Figure 16.8, (B) through (E), on page 557 of the student textbook."



4. The spindle apparatus guides the chromosomes to the equator of the cell during metaphase, pulls separated sister chromatids to opposite poles of the cell during anaphase, and elongates the cell during anaphase.
5. For any organism to develop properly and to remain healthy its cells must divide only at certain times and they must stop dividing at the correct time. This requires a delicate balance among many different regulatory signals. Within a cell, specific protein interactions serve as "start" or "stop" signals for cell division. External factors, such as the presence of particular hormones, the availability of nutrients, and contact with other cells, also play a role. Anything that interferes with regulatory signals can cause the cell cycle to proceed at an uncontrolled rate. The group of diseases that are associated with uncontrolled, rapid cell division is known as cancer. Rather than spending much of their cell cycle as functioning tissue cells, cancerous cells move quickly from one cell division to the next. The result is a fast growing mass of non-functional cells, called a tumour.
6. Spindle fibres consist of microtubules. Without spindle fibres, the chromosomes would not move to the equator of the cell during metaphase or to the poles of the cell during anaphase. Nor would the cell elongate during anaphase. As a result, the daughter cells would not receive an equal number of chromosomes.
7. An error most likely occurred in anaphase. If the sister chromatids were pulled apart but failed to separate to opposite poles in this phase, following cytokinesis, one cell would have 92 chromosomes (chromosomes would be single, not chromosome pairs; therefore, there would be 92) and the other would have none.

Connections (Nature of Science)

Regenerating the Sense of Hearing?

Student Textbook page 562

Teaching Strategies

- You may wish to group your students into teams of two or three to do the research necessary to answer the questions in this feature. If so, consider assigning a specific role (job) to each member of the group such as organizer (keeps the group organized and on task), print researcher (looks for print articles in the library), online researcher (searches the Internet for the required information), and writer (compiles all of the information).
- You can also match this activity to the skills and attitude components of the program of studies. For example, you can focus on the objectives for conducting research, namely:
  - evaluating sources of information for adequacy, relevance, reliability, and bias (skill);
  - collecting and compiling relevant information from print and electronic sources (skill);
  - using a multi-perspective approach (attitude);
  - critically evaluating evidence and arguments (attitude); and
  - comparing risks and benefits of applying scientific knowledge and technologies (STSE concept).

Answers to Questions

1. Although there are many possible causes of hearing loss, the causes can be divided into two basic types—conductive and sensorineural hearing loss. Conductive hearing loss is caused by anything that interferes with the transmission of sound from the outer to the inner ear. Possible causes include middle ear infections; collection of fluid in the middle ear; blockage of the outer ear (by wax); damage to the eardrum by infection or an injury; otosclerosis, a condition in which the ossicles of the middle ear become immobile due to growth of the surrounding bone; and rarely, rheumatoid arthritis, affecting the joints between the ossicles (middle ear bones). Sensorineural hearing loss is due to damage to the pathway for sound impulses from the hair cells of the inner ear to the auditory nerve and the brain. Possible causes include age-related hearing loss—the decline in hearing that many people experience as they get older; injury to the hair cells caused by loud noise; viral infections of the inner ear that may be caused by mumps or measles; viral infections of the auditory nerve that may be caused by mumps and rubella; certain drugs, such as aspirin, quinine, and some antibiotics, which can affect the hair cells; acoustic neuroma, a non-cancerous tumour affecting conduction of nerve impulses by the auditory nerve; infections or inflammation of the brain or brain covering, for example, meningitis; multiple sclerosis; brain tumours; and strokes. Hearing loss can be prevented in several ways. Protect your ears from loud noises by either avoiding them or by wearing ear protection, such as earplugs or ear protectors. Covering your ears with your hands and opening your mouth will help protect intense vibrations from reaching the eardrum. Keep the volume low when using earphones or car stereos, as the sounds are accentuated in enclosed spaces, such as a car. Get the proper immunizations for measles, mumps, and other diseases, and get medical attention for all ear infections.
2. The retinoblastoma (Rb) protein exists in two states: phosphorylated (pRb) and non-phosphorylated (Rb). It is a major control factor in regulating passage of cells from G1 phase into S phase, and through the cell cycle. During the mammalian cell cycle, pRb prevents the cell from replicating damaged DNA by preventing its progression through the cell cycle from G1 phase to S, or synthesis phase. If pRb could be regulated so that it does not prevent support cell regeneration, this might help contribute to a cure for nerve deafness. Further, if nerve deafness results from a tumour, treatment with pRb could possibly arrest the growth of the tumour, preventing the

tumour cells from proceeding from G1 phase to S phase and replicating the DNA.

16.3 The Formation of Gametes

Student Textbook pages 563-572

Section Outcomes

Students will:

- define and explain the significance of chromosome number in gametes
- examine how meiosis results in the production of gametes
- describe the ways in which meiosis contributes to genetic variation
- compare the processes of oogenesis and spermatogenesis
- design a model to simulate the processes of meiosis and mitosis
- model the processes of crossing over between chromosomes
- compare the formation of fraternal and identical twins

Key Terms

meiosis
reduction division
recombination
meiosis I
meiosis II
germ cells
synapsis
tetrad
non-sister chromatids
crossing over
nondisjunction
spermatogenesis
oogenesis
spermatogonium
primary spermatocyte
secondary spermatocyte
spermatids
oogonium
primary oocyte
secondary oocyte
first polar body
second polar body

Biology Background

- The events that occur in meiosis I (synapsis of homologous chromosomes, crossing over, separation of homologous chromosomes in different cells) are unlike any of the events that occur in mitosis. Instead, mitosis II more closely resembles mitosis than does meiosis I. In both meiosis II and mitosis, individual chromosomes containing two sister chromatids align on the metaphase plate. Then the centromeres divide, and the sister chromatids of each chromosome pair migrate to opposite poles. The main difference between meiosis II and mitosis is that in meiosis II there is only one set of chromosomes in each cell. Also, in meiosis II, 2 cells divide into 4 cells, while in mitosis, 1 cell divides into 2.
- When chromosomes or chromatids do not separate as they should during anaphase I and II of meiosis, nondisjunction is said to occur. Monosomy, the loss of a chromosome in nondisjunction, can result in several congenital genetic conditions, the most common being Turner syndrome (loss of one X or Y chromosome). A larger number of genetic conditions result from trisomy, the gain of an extra chromosome due to nondisjunction, including Down syndrome (trisomy 21), Patau syndrome (trisomy 13), Edward syndrome (trisomy 18), Triple-X syndrome (trisomy X in females), Klinefetter syndrome (trisomy X in males), and Jacobs syndrome (trisomy Y in males). While monosomy and trisomy may occur in other chromosomes, these conditions are most often lethal. Partial monosomy or trisomy may also occur when only one segment of a chromosome is lost or in excess.

Teaching Strategies

- Use **BLM 16.3.1 (OH) Fertilization** during discussions of fertilization. This may be a review for some students.
- Use **BLM 16.3.2 (OH) The Phases of Meiosis** as an overhead teaching tool or photocopy and distribute as a handout, allowing students to write notes directly on the figure while you discuss the events that occur during each phase of meiosis. Go through the steps slowly and in detail. It is worth spending a lot of time to help students develop a clear picture of meiosis in their minds. **BLM 16.3.3 (HAND) The Phases of Meiosis Exercise** can be assigned to students to further reinforce this process.
- Closing all books, ask students to go to the board and draw the phases of mitosis. Each student should draw a different phase. When the first student has completed prophase I, the next student should go to the board and draw metaphase I, and so forth, until all the phases are complete. If a student gets stuck, ask the other students in the class to provide suggestions to help the student at the board complete his or her diagram.
- **BLM 16.3.6 (OH) Potential Genetic Recombination of Diploid Offspring** and **BLM 16.3.7 (OH) Crossing Over** will help clarify the roles independent assortment and crossing over play in ensuring genetic recombination among gametes.
- Have students create their own comparison of mitosis and meiosis. This may be in any form they choose—a table, a diagram, a digital comparison, etc. Students can do this individually, in partners, or in groups. Another option is to photocopy and distribute **BLM 16.3.4 (OH) Comparing Meiosis and Mitosis** for students to refer to and/or assign **BLM 16.3.5 (HAND) Comparing Meiosis and Mitosis Worksheet** to provide students with further practice questions. **BLM 16.3.4 (OH) Comparing Meiosis and Mitosis** also functions as a guide to Investigation 16.C: Modelling to Compare Meiosis and Mitosis.

- Have students make an old-fashioned "flip book" for each of the stages of meiosis I and meiosis II. Have students draw each step on a plain 7.5 x 13 cm index card.
- Check with your local media distribution outlet to see if they have any videos that discuss meiosis. It is usually easier for students to see these events in real time rather than simply looking at illustrations in a textbook.
- Arrange to have a computer, Internet access, and an LCD projector in your room. There are many web sites that have video and/or animations that deal with meiosis. Related web links can be found at **www.alberta.biology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links.

Answers to Questions for Comprehension

Student Textbook page 563

Q20. The two key outcomes of meiosis are reduction and recombination. Meiosis is sometimes referred to as a reduction division because it is a form of cell division that produces daughter cells with fewer chromosomes than the parent cells. Recombination is a key outcome of meiosis as the products of meiosis have different combinations of genes. This genetic recombination gives rise to offspring that are genetically distinct from one another and their parents.

Q21. Meiosis is a special type of cell division that occurs only in reproductive organs. Meiosis produces genetically unique reproductive cells called gametes. The gametes, either eggs or sperm, are haploid (n), which means that they contain only one copy of each type of chromosome that the diploid (2n) parent cell contains. This differs from the function of mitosis, which creates new, genetically identical diploid cells to enable tissue growth, maintenance, and repair.

Q22. Meiosis occurs only in reproductive organs.

Figure 16.11

Student Textbook page 564

The events that occur in Meiosis I (synapsis of homologous chromosomes, crossing over, separation of homologous chromosomes into different cells) are unlike any events in mitosis. Meiosis II more closely resembles mitosis than meiosis I does. In meiosis II and mitosis, individual chromosomes containing two sister chromatids align on the metaphase plate. Then the centromeres divide and the sister chromatids are pulled to opposite poles as spindle fibres shorten. However, in meiosis II, there is only one set of chromosomes in each cell, while there are two sets in mitosis. Also, only one cell divides in mitosis, while two divide in meiosis II.

Answers to Questions for Comprehension

Student Textbook page 566

Q23. Meiosis I begins with prophase I. In prophase I, each pair of homologous chromosomes align side-by-side in a formation called a tetrad. This process is called synapsis. It is during prophase I that crossing over of homologous chromosomes occurs. In the next phase, metaphase I, spindle fibres attach to the centromeres of each chromosome and guide each tetrad to the equator of the cell where the chromosomes line up as homologous pairs. Independent assortment occurs in this phase. During anaphase I, the spindle fibres shorten, causing the homologous chromosomes to separate from one another and move to opposite poles of the cell. Because the sister chromatids are still held together, the centromeres do not split as they do in mitosis. The result is that a single chromosome (made up of two sister chromatids) from each homologous pair moves to each pole of the cell. Next, in telophase I, the homologous chromosomes begin to uncoil and the spindle fibres disappear. The cytoplasm is divided, the nuclear membrane forms around each group of homologous chromosomes, and two cells are formed. (Some cells move directly from anaphase I to meiosis II). The phases of meiosis II are similar to the phases of mitosis; however, each cell that enters meiosis II is haploid, although it consists of replicated chromosomes. Each cell proceeds through prophase II, in which the centrioles move to opposite poles and the nuclear membrane breaks down; metaphase II, in which the chromosomes line up at the equator; anaphase II, in which the centromeres split and the chromatids are pulled to opposite poles; and telophase II, in which the nuclear membrane forms around each separated set of chromosomes. At the end of meiosis II, the four new daughter cells are still haploid, but they contain single unreplicated chromosomes.

Q24. The result of mitosis is two daughter cells with exactly the same number of chromosomes as the parent cell ($2n$). The result of meiosis is four cells with half the number (n) of chromosomes as the parent cell.

Q25. During crossing over, homologous chromosomes synapse during prophase I. While they are lined up side-by-side, non-sister chromatids exchange pieces of chromosome. As a result of crossing over, individual chromosomes contain some genes of maternal origin and some genes of paternal origin. Independent assortment occurs in metaphase I. Chromosomes are arranged in homologous pairs along the equator of the cell. In each pair, the chromosome of maternal origin is oriented toward one pole of the cell while the chromosome of paternal origin is oriented toward the other pole. This orientation of each pair of homologous chromosomes is independent of the orientation of the other pairs. Therefore, some maternal homologues and some paternal homologues face each pole of the cell. This means that the resulting gametes will have different combinations of parental chromosomes.

Biology File: Try This

Student Textbook page 567

Trisomy could occur as a result of nondisjunction of chromosome 21 in either anaphase I or anaphase II in either the maternal or paternal parent.

Thought Lab 16.1: Nondisjunction Syndromes

Student Textbook page 567

Purpose

Students will research a syndrome resulting from nondisjunction and present their findings in a print or electronic media format.

Outcomes

30–C1.5k

Advance Preparation

When to Begin	What to Do
1 –2 weeks before	■ Book computer and/or library resources for student research.
1 day before	Photocopy **BLM 16.3.12 (HAND) Thought Lab 16.1: Nondisjunction Syndromes.**

Time Required

- 1-2 hours for research
- 1 hour to create presentation of findings

Helpful Tips

- Use **BLM 16.3.12 (HAND) Thought Lab 16.1: Nondisjunction Syndromes** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 16.3.12A (ANS) Thought Lab 16.1: Nondisjunction Syndromes Answer Key**.
- There are a number of web sites that provide information on nondisjunction syndromes. Web links related to this investigation can be found at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links. To save time, you may want to assign nondisjunction syndromes to students and provide them with a list of relevant web sites.
- This Thought Lab can also be completed in groups or partners.

Answers to Analysis Questions

1. to **3.** Accept any well-researched and clearly presented answers.

Assessment Options

- Assess student presentations.
- Collect and assess students' answers to the Analysis questions.
- To assess group work, use Assessment Checklist 3 Performance Task Self-Assessment and/or Assessment Checklist 4 Performance Task Group Assessment. (See Appendix A.)
- To assess research, use Assessment Checklist 7 Independent Research Skills. (See Appendix A.)

Answers to Questions for Comprehension

Student Textbook page 568

26. Sometimes chromosomes or chromatids do not separate as they should during meiosis. This phenomenon is called nondisjunction. Nondisjunction occurs in anaphase I and II of meiosis. In anaphase I, nondisjunction occurs when homologous chromosome pairs do not separate to opposite poles; instead, one entire pair is pulled toward the same pole together. In anaphase II, nondisjunction occurs when sister chromatids do not separate to opposite poles; instead, both sister chromatids are pulled toward the same pole together. As a result, nondisjunction produces gametes that have either too few or too many chromosomes. When one chromosome is lost due to nondisjunction, it is called monosomy. In this case, the gamete is missing one chromosome of a homologous pair. Nondisjunction can also result in trisomy—the gain of an extra chromosome.

Investigation 16.C: Modelling to Compare Mitosis and Meiosis

Student Textbook page 568

Purpose

Students will design a model to simulate and compare behaviours of chromosomes that are undergoing mitosis and meiosis.

Outcomes

30–C1.2s

Advance Preparation

When to Begin	What to Do
Several days before	■ Have students brainstorm to come up with the materials they will need to complete their model.
1 day before	■ Photocopy **BLM 16.3.13 (HAND) Investigation 16.C: Modelling to Compare Mitosis and Meiosis**. ■ Photocopy **BLM 16.3.4 (OH) Comparing Meiosis and Mitosis**, if using.

Materials
As per student design.

Time Required

- 30 minutes for brainstorming and planning
- 1 to 2 hours for building their models and developing their presentations
- 1 hour for presentation of models

Helpful Tips

- Use **16.3.13 (HAND) Investigation 16.C: Modelling to Compare Mitosis and Meiosis** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **16.3.13A (ANS) Investigation 16.C: Modelling to Compare Mitosis and Meiosis Answer Key**.
- You may also choose to photocopy and distribute **BLM 16.3.4 (OH) Comparing Meiosis and Mitosis**. This BLM provides students with side-by-side diagrams of both processes.
- A few days in advance, provide 30 minutes or so at the end of a class to group students and to give them time to brainstorm what they will use to make their models. This will give them time to gather the materials, if required.
- Consider having students develop a storyboard as part of their planning process. This will force them to think everything through before they start constructing their model.
- Make sure that you establish firm timelines for the project and presentation to reduce the chances of students wasting valuable class time.
- Provide students with your evaluation tool (rubric) prior to starting this activity.

Safety Precautions

Discuss safety precautions with each group based on the model that they are going to use to compare meiosis and mitosis.

Answers to Evaluate and Communicate Questions

1. Accept any well-presented answers that gauge the effectiveness of students' models and presentations.
2. Effective models are well thought out (planned), meet all of the design specifications, and accurately depict mitosis and meiosis.
3. Accept any answer that clearly indicates and provides an explanation for the proposed changes.
4. Meiosis is well suited to the production of gametes because it reduces the chromosome number in half (haploid) and provides the opportunity to increase genetic variation (via crossing over and independent assortment) in the species. Meiosis is not suited to the purposes of the cell cycle for similar reasons. Because of the reduction division that occurs in meiosis, the daughter cells are no longer identical to the parent cell, a requirement of the cell cycle. Similarly, crossing over and independent assortment lead to genetic variation, which is not desired in the cell cycle. Mitosis is better suited to the cell cycle because daughter cells are identical to parent cells—each has an exact replica of the parent cell's genetic material. Thus mitosis creates an identical cell that can continue through the cell cycle to produce more identical cells, unlike meiosis, where genetic reduction and variation would result in cells that differ from the parent cell and would eventually bring the cell cycle to a halt.

Assessment Options

- Assess students' presentations.
- Collect and assess students' answers to Evaluate and Communicate questions.
- To assess group work, use Assessment Checklist 3 Performance Task Self-Assessment and/or Assessment Checklist 4 Performance Task Group Assessment. (See Appendix A.)

Answers to Questions for Comprehension

Student Textbook page 570

Q27. Key similarities between spermatogenesis and oogenesis are as follows: both processes begin with a diploid germ cell; both result in haploid gametes; both under go meiosis I and II. Key differences include the following: oogenesis occurs in females, while spermatogenesis occurs in males; oogenesis begins before puberty (cells are arrested at prophase I) while spermatogenesis begins at puberty; oogenesis is arrested twice, once at prophase I and once at metaphase II, while spermatogenesis is not;

oogenesis results in the formation of polar bodies due to asymmetrical cytokinesis, while spermatogenesis does not; oogenesis results in one viable gamete, while spermatogenesis results in four.

Q28. The unequal division of cytoplasm means that only one egg cell is produced from the division of the secondary oocyte. This egg cell, however, contains a large quantity of nutrients that the zygote requires prior to implantation, thus helping to ensure the health of the zygote.

Q29. In humans, spermatogenesis continues from puberty until old age. This process differs from oogenesis where, in human females, more than a decade separates the events of meiosis I and II. In oogenesis, the primary oocytes begin meiosis I before birth, but cell division stalls in prophase I. The cells remain in this suspended state until puberty. At puberty, a hormone signal triggers a single primary oocyte to resume meiosis and the primary oocyte completes meiosis I. The secondary oocyte that results only completes a second meiotic division if it comes into contact with a sperm cell and fertilization occurs. The timing of oogenesis and spermatogenesis are specific to their functions as follows: the timing of oogenesis allows female gamets to undergo an extended period of growth, which is necessary to accumulate resources for early embryonic stages of development. Male gamets do not require the extended growth phase and can be produced continually.

Student Textbook page 571

Q30. While most women release only a single secondary oocyte at each ovulation, occasionally more than one secondary oocyte may be released. If both of these oocytes are fertilized and successfully implant in the uterus, fraternal twins may be born. On the other hand, if a single zygote or blastocyst divides into two separate bodies in the first few days of embryonic development, identical twins may be born.

Figure 16.18

Student Textbook page 571

Students may suggest that scientists could apply their understanding of meiosis when studying human genetic birth defects such as Down syndrome. They could also use it to investigate new birth control methods.

Section 16.3 Review Answers

Student Textbook page 572

1. The process of meiosis produces haploid gametes from diploid parent cells as is necessary for sexual reproduction. Meiosis also contributes to genetic variation by producing many genetically different gametes. Variation in gametes results from crossing over, in which non-sister chromatids exchange chromosome sections during prophase I. Also in metaphase I, homologous chromosomes assort independently, which allows for different combinations of parental chromosomes in the gametes.

2. Meiosis occurs in spermatogonial cells in the testes in males, and in the oogonial cells in the ovaries of females.

3. At the end of meiosis II, four haploid cells have been formed from the original parent cell.

4. Assuming that no crossing over occurs, a diploid organism with four pairs of chromosomes can produce 2^4 (16) genetically distinct gametes.

5. In prophase I of meiosis, the chromosomes exchange portions of the non-sister chromatids in the process known as crossing over, as shown in the image. Crossing over is significant because it results in the production of many genetically different gametes by an organism, which contributes to genetic variation in the species.

6. (a) Nondisjunction occurs when chromosomes or chromatids do not separate and move to the poles of the cell in anaphase of meiosis I or II. This results in gametes with an extra chromosome or a missing chromosome. Crossing over is a process that occurs during prophase I of meiosis, in which chromosomes exchange of portions of non-sister chromatids.

(b) A primary oocyte is the first functional egg cell formed by mitosis from oogonial cells in the ovaries. The primary oocyte then undergoes meiosis I to produce a secondary oocyte, the second functional egg cell. The secondary oocyte fully completes meiosis II upon fertilization.

(c) Spermatids are four haploid cells formed after meiosis II in spermatogenesis. The spermatids differentiate into sperm cells by passing through a series of developmental stages. The nucleus and certain enzymes are organized into a "head" region. The midsection holds many mitochondria that provide energy for the sperm. A long tail-like flagellum provides locomotion.

(d) Oocytes are functional egg cells that are formed via mitosis and meiosis in oogenesis. During these divisions, other egg cells are formed, known as polar bodies, which have much less cytoplasm than the oocytes. This occurs because the division of the cytoplasm between the oocyte and the polar body is unequal (known as asymmetrical cytokinesis). The oocyte requires nutrients found in the cytoplasm to sustain it following fertilization and during its long journey in the Fallopian tube to the uterus, where it again receives nutrients. Polar bodies are non-functional and soon degenerate.

7. (a) metaphase (mitosis): In metaphase of mitosis, 23 pairs of homologous chromosomes occur as linked sister chromatids (92 chromatids in total). (Note: Of these 23 pairs of chromosomes, males actually have two

nonhomologous sex chromosomes, the X chromosome and the Y chromosome.)

(b) metaphase I (meiosis): In metaphase I of meiosis, twenty-three pairs of homologous chromosomes are arranged in pairs. Each homologous chromosome contains 2 linked sister chromatids, and is part of a tetrad of four chromatids.

(c) metaphase II (meiosis): In metaphase II of meiosis, each cell contains twenty-three chromosomes, one member of the earlier homologous chromosome pairs. Each chromosome consists of a pair of linked sister chromatids.

8. No, identical twins cannot be different sexes. Identical twins are born if a single zygote, during its first two weeks of embryonic development, divides into two separate bodies. Because the sex of the zygote is already determined upon fertilization, each twin must be the same sex.

9. In metaphase I of meiosis, the chromosome tetrads align at the cell equator. The feature of this alignment that contributes to genetic diversity is independent assortment.

10. A drawing or descriptive answer should reflect understanding that nondisjunction occurs in either anaphase I or anaphase II, in which an X chromosome fails to move to the pole of the cell, resulting in an oocyte or spermatid without an X chromosome.

16.4 Reproductive Strategies

Student Textbook pages 573-580

Section Outcomes

Students will:

- describe the diversity of reproductive strategies among living organisms
- evaluate the advantages and disadvantages of sexual and asexual reproduction
- research and present information about contrasting reproductive strategies
- assess how research on plant and animal reproduction has affected the development of new reproductive technologies

Key Terms

asexual reproduction
sexual reproduction
binary fission
conjugation
pilus
budding
vegetative reproduction
fragmentation
parthenogenesis
spore
alternation of generations
sporophyte
gametophyte

Biology Background

- Bacteria generally reproduce asexually. However, to increase diversity and share the gene pool, they can also transfer genetic material from one bacterium to another via conjugation. The ability to perform this transfer is conferred by a set of genes, which are called F, or fertility, genes. These genes can exist on a small, circular piece of DNA (called an F-plasmid) that replicates independently from the bacterial chromosome, or they can be integrated into the chromosome. The bacterium containing this gene (often parochially called the "male" bacterium) extends a bridging structure (called a pilus) to a neighbouring bacterium. The two cells then are drawn together, and the pilus forms a channel through which DNA is transferred. The receiving bacterium then divides during binary fission. Some eukaryotes, such as certain fungi and algae, also reproduce via conjugation. Plasmid conjugation is a relatively rare event. Nobel Prize-winning scientist Joshua Lederberg discovered the process in 1945 when experimenting with mutant strains of *E.coli*.

Teaching Strategies

- This section provides an overview of a number of reproductive strategies. Use **BLM 16.4.1 (OH) Binary Fission in Bacterial Cell, BLM 16.4.2 (OH) The Life Cycle of a Fern, BLM 16.4.3 (OH) The Life Cycle of Moss, BLM 16.4.4 (OH) The Life Cycle of a Conifer**, and **BLM 16.4.5 (OH) The Cnidarian Life Cycle** to support your presentations on these subjects. You may also want to use these BLMs as handouts and allow the students to take notes directly on the worksheets while you discuss the different concepts in this section. **BLM 16.4.7 (HAND) Comparing Life Cycles Exercise** provides students with further practice in differentiating between these life cycles.
- In **BLM 16.4.6 (HAND) Create an Organism Exercise**, students are asked to create an organism, giving consideration to life cycle and reproductive processes. This BLM can work well as both an individual or group exercise.

Answers to Questions for Comprehension

Student Textbook page 573

Q31. Asexual reproduction is a reproductive process in which a parent organism produces genetically identical offspring. Sexual reproduction involves the production of gametes by meiosis, followed by fertilization between genetically distinct parental gametes to produce genetically distinct offspring.

Student Textbook page 574

Q32. Prokaryotes, such as bacteria, have a single, circular chromosome and no nucleus. They reproduce asexually by replicating the DNA and then distributing one complete copy of the DNA into each of two daughter cells. There are no spindle fibres or centrioles, as in eukaryotic cells, that divide the nucleus by mitosis, nor is there a nuclear envelope.

Q33. Conjugation is the transfer of genetic material from one cell to another by cell-to-cell contact through a bridging structure (pilus). This results in a single cell with new genetic material. Neither meiosis, nor gamete formation occurs. In sexual reproduction, haploid gametes that contain half the genetic material of the diploid organism are formed by meiosis. Gametes unite in the process of fertilization and form a new diploid organism that is genetically unique.

Student Textbook page 575

Q34. Plants can reproduce asexually via vegetative reproduction. In this process, a new plant develops at the end of a leaf, stem, or root of the parent plant. Another form of asexual reproduction is called fragmentation. During this process a new plant develops from a fragment (portion) of a parent plant, such as a single leaf, tuber, or a cutting from the parent plant. Both of these methods result in a new plant that is genetically identical to its parent.

Q35. Parthenogenesis is considered to be a form of asexual reproduction because the egg is not fertilized by the male gamete. As such, it is the sole source of genetic material for the creation of an embryo. The resulting offspring is genetically identical to the parent.

Q36. A spore is a structure that contains genetic material and cytoplasm surrounded by a protective sheath or wall. The wall protects the contents until conditions are favourable, at which point the spore wall opens and the organism begins to develop. Because spores tend to be very small, they are readily dispersed in water and by the wind. Spores may be haploid or diploid, and not all spores are the product of asexual reproduction. While some organisms produce spores by mitosis, others produce spores by meiosis.

Biology File: Web Link

Student Textbook page 575

This web link provides students with an opportunity to learn about current scientific research in a field they have just learned about. Students will likely discover that parthenogenesis is being studied as a way to stimulate oocytes to produce embryonic-like stem cells that could be used in the future to treat any number of diseases and disorders. The ultimate goal is to harvest human embryonic stem cells without fertilized eggs or cloned embryos, which are the two most popular and controversial methods of doing such research.

Answers to Questions for Comprehension

Student Textbook page 577

Q37. The life cycle of plants consists of a haploid generation and a diploid generation that alternate. This is called the alternation of generations. Strictly speaking, the term "alternation of generations" refers to this alternation of diploid and haploid generations. This reproductive strategy is found only in plants. Some animal life cycles, however, alternate between asexually-reproducing and sexually-reproducing phases in a process called the "alternation of reproductive cycles."

Thought Lab 16.2: Comparing Reproductive Strategies

Student Textbook page 579

Purpose

The purpose of this activity is to use a table or graphic organizer to research, analyze, and communicate the advantages and disadvantages of two different reproductive strategies.

Outcomes

- 30–C1.2s

Advance Preparation

When to Begin	What to Do
1-2 weeks before	■ Book computer and/or library resources for student research.
1 day before	■ Photocopy **BLM 16.4.8 (HAND) Thought Lab 16.2: Comparing Reproductive Strategies.**

Time Required

- 1 hour to do research
- 1 hour to construct a table or concept organizer and present findings to class

Helpful Tips

- Use **BLM 16.4.8 (HAND) Thought Lab 16.2: Comparing Reproductive Strategies** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 16.4.8A (ANS) Thought Lab 16.2: Comparing Reproductive Strategies Answer Key**.

- Groups of 2 or 3 students work best for this lab.
- You could speed up the process by assigning organisms for each group to research.
- Many general biology textbooks will include information on the life cycles of different plants and animals. Ask your librarian to pull out a selection of biology textbooks and have them available for your students.
- Rather than have students do a presentation, collect their concept organizers and photocopy them for your class. This will give all students the same information and will save the time required to do the presentations.

Answers to Analysis Questions

1. It is unlikely that all groups will come to the same conclusions, as there will be many different advantages and disadvantages of the reproductive strategies used by the various organisms researched. Students may identify factors that account for these differences as environment, characteristics of the organism itself and the population as a whole, etc.

2. There are advantages and disadvantages to both sexual and asexual reproductive strategies. Students may list the advantages and disadvantages of sexual and asexual reproduction as follows:

Sexual reproduction provides populations with a means of adapting to a changing environment (some offspring, for example, may have a greater ability to resist parasites or toxins in the environment or to take advantage of new food sources); competition among siblings may be less if they are genetically diverse; and pairing of homologous chromosomes and crossing over offer opportunities to replace or repair damaged chromosomes. However, sexual reproduction requires the presence of a second organism, may take more time and energy than asexual reproduction, and offspring must often fend for themselves in the environment after birth.

Asexual reproduction is often faster and requires less energy than sexual reproduction; does not require the presence of a second parent organism; and because the daughter organism does not fully separate from the parent until it is capable of independent survival, asexual reproduction may increase chances of survival in some cases. However, asexual reproduction does not allow for genetic variation (offspring are genetic duplicates of the parent).

3. (a) Students may choose any of the forms of reproduction covered in the text (sexual reproduction, asexual reproduction, alternation of generations, or alternation of reproductive cycles).

(b) Student descriptions/illustrations should include the complete cyclical lifecycle and details explaining each stage of the cycle.

(c) Students' answers should clearly explain how the chosen form of reproduction would benefit their organism with specific reference to the organism's environment.

Assessment Options

- Collect and evaluate students' tables or concept organizers.
- Collect and assess students' answers to the Analysis questions.
- To assess group work, use Assessment Checklist 3 Performance Task Self-Assessment and/or Assessment Checklist 4 Performance Task Group Assessment. (See Appendix A.)

Section 16.4 Review Answers

Student Textbook page 580

1. Examples include binary fission, budding, vegetative reproduction, fragmentation, parthenogenesis, and, in some cases, spore formation.

2. Conjugation is shown in the image. You would expect to see conjugation in bacteria, as well as in some types of algae and fungi.

3. Budding and fragmentation are similar in that the offspring produced are genetically identical to the parent. Both develop from a portion of the parent. Budding and fragmentation are different in that the bud forms from the parent and remains attached to the parent until it is mature, at which point it separates. In fragmentation, a piece of mature tissue from the parent separates and begins to grow into a new, complete organism on its own.

4. (a) Parthenogenesis

(b) None of the offspring would be male, as the female parent fish would not have any copies of the Y chromosome and male fish have not fertilized the eggs.

5. Student diagrams should include the following:

male (diploid) → meiosis → sperm (haploid)

fertilization (diploid) → mitosis → zygote

female (diploid) → meiosis → egg (ovum) (haploid)

6. The life cycles of the moss and the pine tree both involve alternation of gametophyte and sporophyte generations. They differ in that the gametophyte generation of the moss is dominant and the sporophyte generation is dependent on the adult moss. Whereas in the pine, the sporophyte generation is the tree and is dominant, and the gametophyte generation is part of the male and female pine cones.

7. The reproductive advantage of a spore is that it is small and can easily be dispersed by wind and water. Therefore, it has a greater chance of finding a new location with favourable environmental conditions where it will not

compete with the parent organism. Vegetative reproduction does not typically allow for such motility. Offspring produced by vegetative reproduction usually grow close to the parent plant and may have to compete for space and nutrients. Further, spores may be formed by sexual or asexual reproduction. Sexual reproduction allows for the generation of genetic variation in the offspring, thus increasing the population's ability to adapt to a changing environment. Vegetative reproduction is asexual and does not allow for such variation.

8. Advantages of sexual reproduction include the following: genetic variability offers a population a way to adapt to a changing environment; competition among siblings may be reduced if they are genetically diverse; pairing of homologous chromosomes and crossing over offer opportunities to replace or repair damaged chromosomes. Disadvantages of sexual reproduction include: the process is slower than asexual reproduction, which may not allow the offspring to take advantage of favourable environmental conditions; a male and female organism are required to produce gametes; the process requires more energy than asexual reproduction; and offspring are completely separate from their parents at birth and cannot always rely on them for survival.

9. Sexual reproduction could help a population of sea anemones overcome a toxic-waste spill because the free swimming larvae could disperse and avoid the toxins in the water. Genetic variation among the larvae could also enable some organisms to be better able to withstand the toxic effects of the spill.

Chapter 16 Review Answers

Student Textbook pages 582-583

Answers to Understanding Concepts Questions

1. Advances in technology include further development of the microscope and the development of chromosomal stains that enabled the observation of the nuclear contents and processes in cell reproduction.

2. Chromatin are long intertwined threads of DNA surrounding histone proteins. They are located in the nucleus and occur during interphase of the cell cycle. During S phase of interphase, the DNA replicates. Chromosomes are formed at the beginning (prophase) of mitosis and meiosis when the chromatin condenses by successive degrees of coiling. When the chromosomes become visible in mitosis and meiosis, they appear as two strands of identical genetic material held together by a centromere. Each strand is a chromatid. When the chromatids separate in anaphase, the single chromatid is now referred to as a chromosome.

3. The three stages of interphase are Gap or Growth 1 (G1), synthesis (S) phase, and Gap or Growth 2 (G2) phase. In G1 phase, the cell carries out rapid growth and metabolism. During S phase, the DNA is replicated to form two identical sets of genetic material in preparation for division of the nucleus. G2 phase follows S phase, and is a period in which the cell rebuilds it energy reserves and manufactures proteins and other molecules required for cell reproduction.

4. Diagram should be labelled as follows: A = replicated chromosome, B = growing spindle fibres, and C = disappearing nuclear membrane.

5. When two gametes unite and form a zygote, the haploid (n) number of chromosomes in each gamete will be doubled, forming the diploid ($2n$) number of chromosomes found in somatic cells.

6. (a) tissue renewal: mitosis

(b) growth of an embryo: mitosis

(c) production of gametes: meiosis

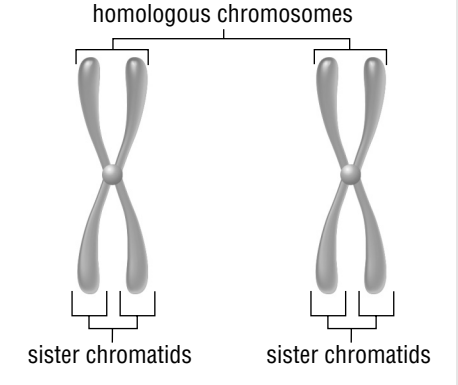
7. (a) mitosis: Root-tip cells are actively dividing and will show mitosis best.

(b) meiosis: The ovule or anther (gonad) of a flower that produce egg cells and sperm nuclei would show meiosis best.

8. The chromatin replicates during synthesis (S) phase of the cell cycle.

9. The diagram on the right shows the chromosomes in metaphase I of meiosis. During metaphase I of meiosis, the chromosomes synapse as homologous pairs. In each pair, one homologous chromosome is positioned on one side of the cell's equator, and the other homologous chromosome is positioned on the other side of the cell's equator. The diagram on the left shows the chromosomes in metaphase of mitosis.

10. (a)



(b) The tetrad arrangement of homologous chromosomes allows crossing over of segments of non-sister chromatids, resulting in genetic variability in the gametes.

11. The two cells following telophase I are haploid, in that each member of the homologous pair of chromosomes moved to an opposite pole of the cell, which then divided into two separate haploid cells.

12. Students may mention any two of the following (example organisms are given in brackets): binary fission (bacteria, and some algae and fungi), budding (yeast and hydra),

vegetative reproductions (strawberries), fragmentation (sea stars, potatoes, and most garden plants), and parthenogenesis (bees, whiptail lizard). Some students may mention asexual spore formation, which is correct, although no specific examples of organisms that form spores asexually are given in the text.

13. In mitosis, the homologous chromosomes do not form tetrads and so there is no crossing over. This is important because, as a consequence, mitosis results in the production of two genetically identical cells.

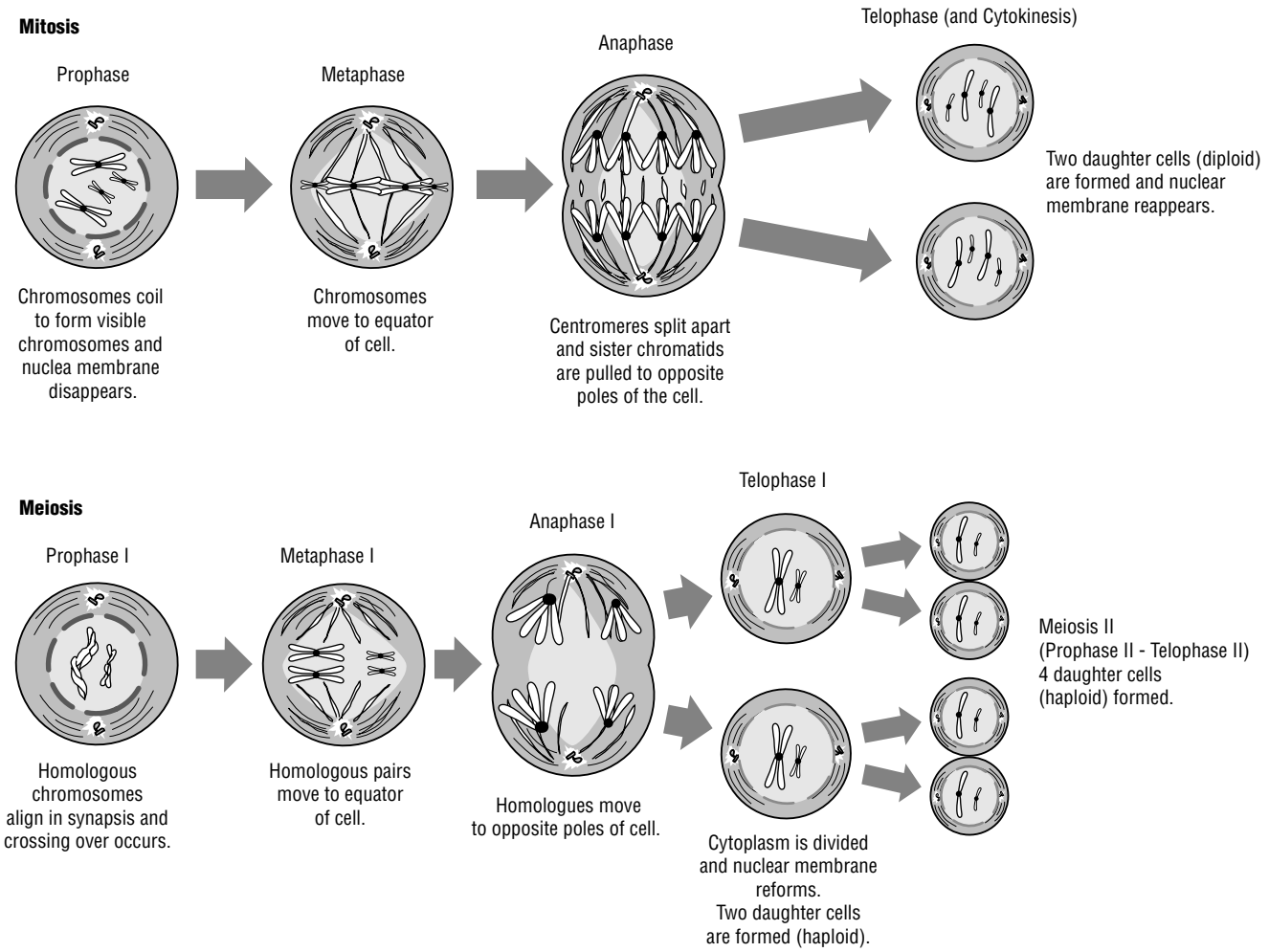
14. Use the chromosome numbers in the following table to complete the table below.

Chromosome Numbers of Some Common Organisms

Organism	Diploid body cell (2*n*)
fruit fly	8
garden pea	14
leopard frog	26
pine tree	24

Cell type and phase	Number of chromosomes	State of chromatin or chromosomes (duplicated or unduplicated)
fruit fly germ cell after telophase I of meiosis	4	duplicated
garden pea germ cell after telophase II of meiosis	7	unduplicated
leopard frog somatic cell in interphase	26	Unduplicated, if not a germinal cell
pine tree gametophyte cell in prophase of mitosis	12	duplicated

15. The top diagram in this question refers to mitosis and the bottom diagram shows meiosis. They should be labelled as shown below:



Answers to Applying Concepts Questions

16. An embryo in the first four weeks of development is more likely to be seriously affected by the same exposure to radiation than a 10-year-old child because the embryo is still actively developing tissues, whereas the 10-year old child is still growing, but has many more mature cells than the embryo.

17. (a) Students may suggest that G1 will be shortened, as this is typically the longest phase in the cell cycle. Others may suggest that none of the phases will be shortened, as all are essential for cell division. Accept any reasonable, well-explained answer.

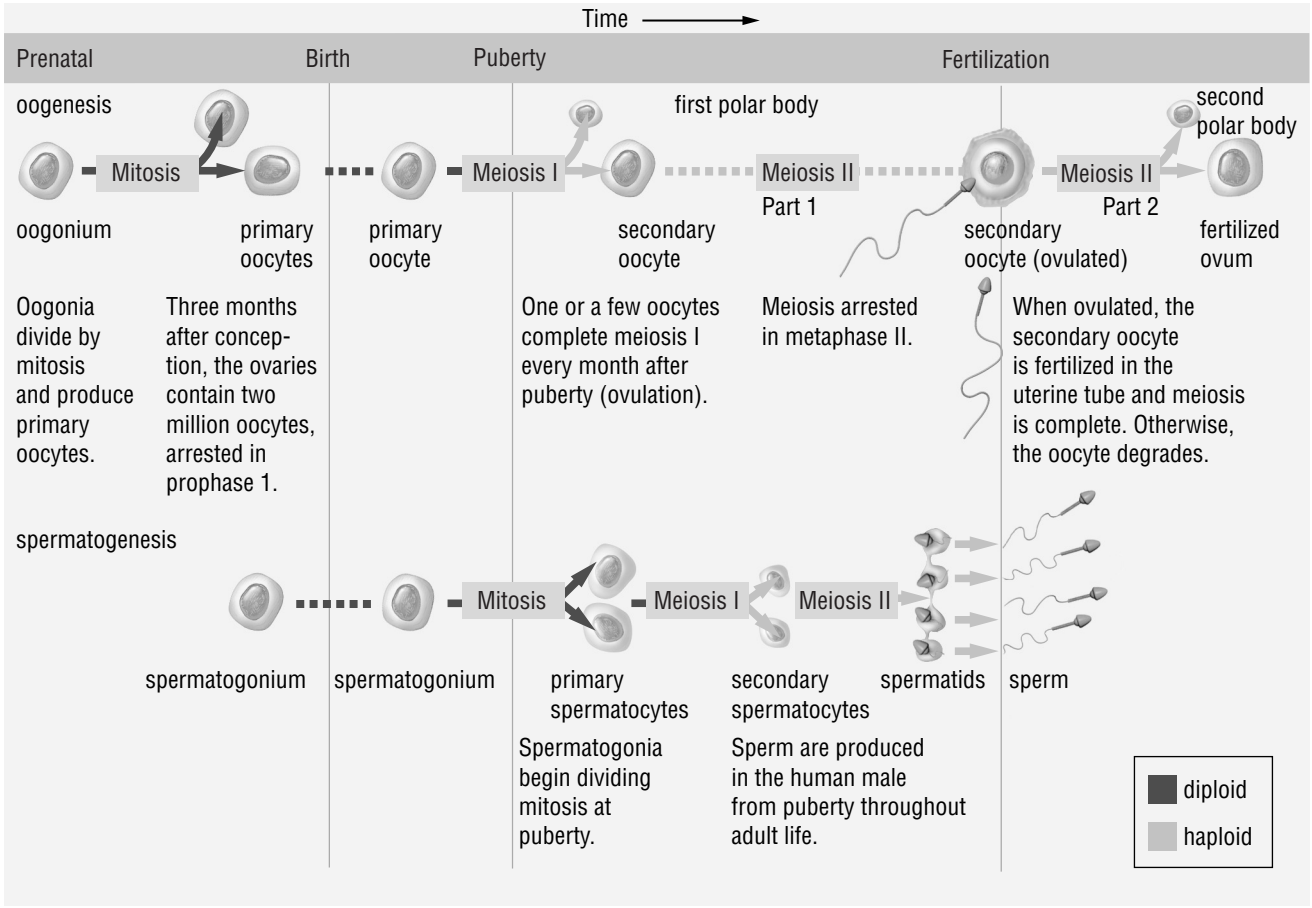
(b) Materials needed to examine the cell cycle of cancerous tissue include: biopsy of skin cancer, biopsy of non cancerous (normal) skin cells, microscope, cell and nuclear stains, microscope slides, reference book that shows cancerous skin cells and immature cells. Students should prepare several stained slides of cancerous and normal cells. Examination of cancerous skin cells should show a larger number of undifferentiated cells and cells in mitosis than in normal skin cells.

18. If a chromosome synapses with a nonhomologous chromosome during meiosis, it is doubtful that the gamete, or the zygote, or the embryo will survive with the resulting chromosomal abnormality.

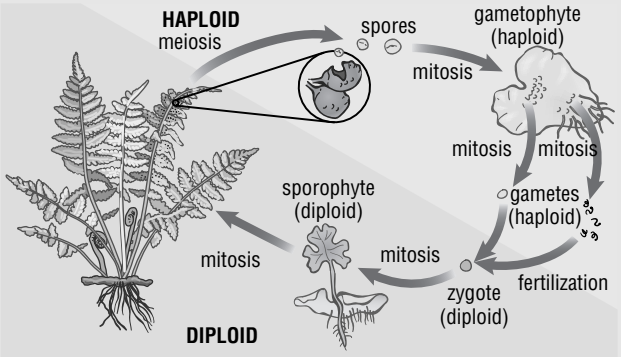
19.

20. Ignoring crossing over, but allowing for multiple pairings of homologous chromosomes, the number of different gametes a human germ cell could produce would be 2^{23} (8 388 608). Ignoring crossing over, the probability that a couple's second child will be genetically identical to their first child is 1 in 8 388 608.

21. Students may draw a sketch of the life cycle of a fern, moss, or conifer. Diagrams should be similar to those shown on the next page. While some students may mention *Cniardia*, technically speaking, the term "alternation of generations" refers to the alternation of diploid and haploid generations, a strategy found only in



plants. *Cniardia* alternates between asexually-reproducing and sexually-reproducing phases, but all forms of the organism remain diploid.



Three important features of this life cycle that students should mention include the following: one generation in the life cycle is haploid and one is diploid; the diploid organism produces spores via meiosis, which are haploid, that divide via mitosis to form a haploid gametophyte; the haploid gametophyte divides via mitosis to produce haploid gametes, and undergoes fertilization to form a diploid zygote, which divides mitotically to form a diploid sporophyte organism.

22. The table below outlines possible student answers identifying the advantages and disadvantages of asexual reproduction:

Advantage	Disadvantage
Because the daughter organism does not fully separate from the parent until it is capable of independent survival, asexual reproduction may increase chances of survival in a hostile environment.	Because offspring are genetically identical to the parent, there is little genetic variation. As a result, offspring may be unable to adapt to a changing environment. Similarly, competition among siblings may be greater because they are identical in their needs.
Does not require the presence of a second organism.	Because pairing of homologous chromosomes and crossing over does not occur, there are fewer opportunities to replace or repair damaged chromosomes.
Carried out with less time and energy. Therefore, may help organisms take advantage of favourable environmental conditions.	

23. (a) Understanding the insect's life cycle could help control the insect population by enabling the development of control mechanisms. For example, if the insect reproduced asexually, there would be little genetic variation among offspring and they would be less likely to adapt to pesticide use over time. If the insects reproduce sexually, introducing sterile insects of the same species into the environment may reduce the number of organisms over time, as fertile insects mate with sterile ones. Collecting, sterilizing, and releasing the insects would similarly result in infertile egg production. Determining the point of the lifecycle (e.g., larvae, pupa, or adult) where the insect is most vulnerable, and then planning a course of action to reduce the insect's numbers is also a viable strategy.

(b) No, asexual reproduction would not prevent migration to other orchards. It would only ensure that the offspring are genetically identical to the parent organism.

(c) Cover each tree with insect netting for flying insects or use some other form of barrier, such as insect tape, for crawling insects.

Answers to Making Connections Questions

24. (a) Mitosis occurs more frequently in a 5-year-old than in a 40-year-old human because the 5- year-old has a higher rate of growth and mitosis, as he or she is actively producing new tissues in his or her development to maturity. The 40 year old is past maturity and the number of cell divisions occurring is declining.

(b) Sample suggestions may include the following: research the number of cell divisions different types of tissues are capable of as they age; research which factors cause tissues to wear out over time; determine if genetic changes that occur from exposure to environmental factors increase cell aging; determine if stem cells are programmed to die after a certain number of cell divisions. This research could be applied to help prevent age-related cosmetic tissue degeneration, disease, and mental deterioration.

25. The script for the students' 15-minute play should include the props that they would use, as well as directions for how they would position the students during each phase of mitosis. For example, a belt or skipping rope could represent the centromere. The students themselves would be the chromatids. Longer ropes could represent the cell membrane and the nuclear membrane. The students should also put this play into context. For example, a student has cut his or her finger and the play will look at how the skin repairs itself by cell division. The script may also include diagrams (a storyboard) of how students will be positioned. Remind your students that the script should not focus on the terminology associated with mitosis, but on the process itself.

26. At this point in the program, students will not be aware of how geneticists use crossing over and recombinants to map chromosomes. This topic is discussed in Chapter 17. As such, accept any well-reasoned argument as to how genes may be mapped. Students may recognize that while crossing over occurs at random points between homologous chromosomes, this is less likely to occur near centromeres and, most importantly, when genes are located in close proximity to each other along a chromosome. The less distance there is between two genes, the less likely it is that a crossover will occur. Scientists use this information to map the relative positions of genes on chromosomes. This question works well when assigned to gifted students.

27. Organisms that can reproduce sexually and asexually often reproduce asexually when nutrients or other favourable environmental factors are present, and sexually when conditions become less favourable (when genetic variation is beneficial). As such, an experiment could be designed to determine the effects of two environmental factors such as temperature (warm or cold), moisture levels (moist or dry), or perhaps the availability of a specific food nutrient on insect reproduction. By studying several populations of the same insect, it is possible to determine the optimum range of each environmental condition for asexual and sexual reproduction. This can be done by counting the number of eggs produced, eggs that hatch, and/or offspring that become fertile adults under different conditions. Once baseline data is obtained for the optimum environmental conditions for both forms of reproduction, this could be the control for testing the effects of different environmental conditions that are consistent with the insect's habitat. Experiments should include a procedure, materials list, hypothesis, list of variables (controlled, manipulated, and responding), and a method of assessing the results. Two different environmental factors should be tested.

28. For artificial chromosomes to behave appropriately during cell division, they would have to be able to replicate prior to mitosis so that genetic material is available for the creation of two daughter cells. They must also be able to condense during prophase. The chromosomes would also need to have centromeres to which spindle fibres could attach, allowing them to assemble at the equator of the cell during metaphase and be pulled to opposite poles during anaphase.

CHAPTER 17 PATTERNS AND PROCESSES IN INHERITANCE

Curriculum Correlation

General Outcome 2: Students will explain the basic rules and processes associated with the transmission of genetic characteristics.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
30–C2.1k describe the evidence for segregation and the independent assortment of genes on different chromosomes, as investigated by Mendel	Section 17.1: Early Theories of Inheritance, p. 586 Developing a Theory of Inheritance: Gregor Mendel's Experiments, p. 587 The Law of Segregation, p. 588 The Law of Independent Assortment, p. 591 Investigation 17.1: Testing the Law of Segregation, p. 592	Questions for Comprehension: 1, 2, p. 587 3, 4, p. 588 5, p. 589 Investigation 17.1, p. 592–593 Section 17.1 Review: 4, p. 598 Chapter 17 Review: 2, p. 620 Chapter 17 Test Unit 7 Review, 4, p. 668
30–C2.2k compare ratios and probabilities of genotypes and phenotypes for dominant/recessive alleles, multiple alleles and incompletely dominant or codominant alleles	Section 17.1: Dominant and Recessive Genes, p. 589 Representing Genetic Crosses, p. 589 Analyzing Genetic Crosses, p. 590 Test Cross, p. 591 The Law of Independent Assortment, p. 591 Incomplete Dominance and Co-dominance, p. 594 Objections to Sutton's Theory, p. 596	Questions for Comprehension: 6–9, p. 590 10–12, p. 593 13–16, p. 595 17, p. 596 Practice Problems: 1, 2, p. 591 3–7, p. 596 Section 17.1 Review: 1, 5–11, p. 598 Chapter 17 Review: 3–10, 14–16, 18, 19, p. 620–621 Chapter 17 Test Unit 7 Review: 5, 10–14, p. 668
30–C2.3k explain the limitations of variability due to gene linkage and the influence of crossing over on assortment of genes on the same chromosome	Section 17.2: Linked Genes and Chromosome Maps, p. 599 Crossing Over and Inheritance, p. 599 Sex-Linked Inheritance, p. 601 Thought Lab 17.1: Mapping Chromosomes, p. 602	Questions for Comprehension: 18, 19, p. 601 Practice Problems 8–10, p. 603 Thought Lab 17.1, p. 602 Section 17.2 Review: 1, p. 609 Chapter 17 Test Unit 7 Review: 7, p. 668
30–C2.4k explain the relationship between variability and the number of genes controlling a trait, e.g., *one pair of genes, as for Rh factor, versus two or more pairs of genes, as for skin colour, height*	Section 17.2: Multiple Alleles, p. 604 Polygenic Inheritance, p. 605 Genes and the Environment, p. 609	Questions for Comprehension: 25, p. 605 26, 27, p. 609 Practice Problems: 11–17, p. 606 Section 17.2 Review: 5, p. 609 Chapter 17 Test

	Student Textbook	Assessment Options
30–C2.5k compare the pattern of inheritance produced by genes on the sex chromosomes to that of genes on autosomes, as investigated by Morgan and others	Section 17.1: Crossing Over and Inheritance, p. 595 Section 17.2: Extending Mendel's Laws, p. 599 Chromosome Mapping, p. 600 Sex-Linked Inheritance, p. 601 Section 17.3: Human Genetics, p. 611 Analyzing a Human Pedigree, p. 611 Autosomal Dominant Inheritance, p. 612 Sex-Linked Traits, p. 613 Thought Lab 17.2: Creating a Pedigree, p. 615 Thought Lab 17.3: Analyzing Pedigrees, p. 617	Questions for Comprehension: 18–21, p. 601 Practice Problems: 18–21, p. 615 Thought Lab 17.2: Analysis, p. 615 Thought Lab 17.3: Analyze, p. 617 Section 17.3 Review: 3–4, p. 617 Chapter 17 Test
Outcomes for Science, Technology, and Society (Emphasis on social and environmental contexts)		
30–C2.1sts explain that decisions regarding the application of scientific and technological development involve a variety of perspectives including social by ■ *evaluating the needs and interests of society and the role of genetic counselling and technology in the identification and treatment of potentially disabling genetic disorders*	Section 17.3: Human Genetic Analysis, p. 614 Connections: Social and Environment Contexts: Biobanks, p. 618	Connections: Social and Environment Contexts, p. 618 Section 17.3 Review: 5, p. 617 Chapter 17 Review: 22, 23, p. 621 Unit 7 Review: 35, 39, 42, 44, 45, p. 670–671
■ *discussing the application of genetic crosses in the development of specific breeds or hybrids*	Section 17.3: Breeding Plants, p. 610 Breeding Animals, p. 611	Questions for Comprehension: 29, p. 611 Section 17.3 Review: 1–2, p. 617 Chapter 17 Review: 12, 14, 18, 19, 25, p. 620–621 Unit 7 Review: 31, 33, p. 670
Skill Outcomes (Focus on scientific inquiry)		
Initiating and Planning		
30–C2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by [bullet] designing a plan for collecting data to demonstrate human inheritance	Thought Lab 17.2: Creating a Pedigree, p. 615	Thought Lab 17.2: Analysis, p. 615
Performing and Recording		
30–C2.2s conduct investigations into relationships between and among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ performing an experiment to demonstrate inheritance of a trait controlled by a single pair of genes, e.g., *albino corn*, Brassica (*Wisconsin fast plant*), Drosophila *or* Arabidopsis ■ designing and performing an experiment to demonstrate that an environmental factor can cause a change in the expression of genetic information in an organism	Investigation 17.A: Testing the Law of Segregation, p. 592 Investigation 17.B: Environmental Influences on Gene Expression, p. 608	Investigation 17.A: Analysis, Conclusions p. 592–593 Investigation 17.B: Analysis, Conclusions Extensions, p. 608

	Student Textbook	Assessment Options
Analyzing and Interpreting		
30–C2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ interpreting patterns and trends in data by predicting, quantitatively, the probability of inheritance from monohybrid, dihybrid and sex-linked inheritance by	Launch Lab: Coin Toss, p. 585 Investigation 17.A: Testing the Law of Segregation, p. 592	Launch Lab: Analysis, p. 585 Practice Problems: 9, 10, p. 603 11–13, p. 606 Investigation 17.A: Analysis, Conclusions p. 592–593 Section 17.1 Review: 5, p. 598 Chapter 17: 8–17, p. 620
■ using Punnett squares, interpret patterns and trends in data associated with monohybrid, dihybrid and sex-linked patterns of inheritance	Investigation 17.A: Testing the Law of Segregation, p. 592	Investigation 17.A: Analysis, Conclusions p. 592–593 Practice Problems 9, 10, p. 603 11–13, p. 606 Section 17.2 Review: 2, 3, 5, p. 609 Chapter 17 Review: 5, p. 620 Unit 7 Review: 14, 31, p. 668–670
■ performing, recording and explaining predicted phenotypic ratios versus actual counts in genetic crosses to show a relationship between chance and genetic results	Investigation 17.A: Testing the Law of Segregation, p. 592	Practice Problems: 3–7, p. 596 Investigation 17.A, p. 592–593 Section 17.1 Review 5–9, p. 598 Chapter 17 Review: 2, p. 620 Unit 7 Review: 10–12, 14, p. 668
■ drawing and interpreting pedigree charts from data on human single-allele and multiple-allele inheritance patterns, e.g., *hemophilia, blood types* ■ analyzing crossover data for a single pair of chromosomes to create a chromosome map showing gene arrangement and relative distance	Thought Lab 17.2: Creating a Pedigree, p. 615 Thought Lab 17.3: Analyzing Pedigrees, p. 617 Section 17.1: Analyzing Genetic Crosses, p. 590 Section 17.2: Linked Genes and Chromosome Maps, p. 599 Crossing Over and Inheritance, p. 599 Thought Lab 17.1: Mapping Chromosomes, p. 602	Practice Problems: 18–21, p. 615 Thought Lab 17.2: Analysis, p. 615 Thought Lab 17.3: Analyze, p. 617 Section 17.3 Review: 3, p. 617 Chapter 17 Review: 31, p. 621 Unit 7 Review: 28–30, p. 669–670 Practice Problems: 1, 2, p. 591 Thought Lab 17.1, p. 602 Section 17.1 Review: 6–9, p. 598 Chapter 17 Review: 20, p. 621
■ *providing a concluding statement on assortment of linked genes*	Section 17.1: Summary, p. 597–598 Section 17.2: Linked Genes and Chromosome Maps, p. 599	Section 17.2 Review: 1, p. 609 Chapter 7 Review: 7, p. 620 Unit 7 Review: 9, p. 668

	Student Textbook	Assessment Options
■ *identifying limitations of data associated with phenotypic ratios for small populations in which the ratios may not conform with the theoretical ratios expected*	Thought Lab 17.1: Mapping Chromosomes, Part A, p. 602	Thought Lab 17.1, Part A, p. 602 Section 17.1: 7–9, 11, p. 598 Section 17.2: 4, p. 609 Chapter 17 Review: 16, p. 620 Unit 7 Review: 31, p. 670
Communication and Teamwork		
30–C2.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ *working cooperatively with team members to investigate a monohybrid cross, e.g., tongue rolling, attached ear lobes and solve problems as they arise*	Thought Lab 17.2: Creating a Pedigree, p. 615	Thought Lab 17.2: Analysis, p. 615 Chapter 7 Review: 23, p. 621 e.g., Unit 7 Review: 37–39, 45, 48

Chapter 17

Patterns and Processes in Inheritance

Student Textbook pages 584–621

Chapter Concepts

17.1 Laying Foundations: Peas, Patterns, and Probabilities

- All somatic cells of diploid organisms have two alleles (copies) of each gene. When a gamete forms, it receives only one of these two alleles.
- The distribution of alleles in gametes is random.
- The inheritance of characteristics follows predictable patterns.

17.2 Extending Mendel's Laws: More Patterns and Probabilities

- Genes are arranged in a linear manner along chromosomes.
- Alleles for genes that are close together on the same chromosome do not assort independently.
- The probability of recombination of linked genes increases with the map distance between these genes.
- Genes that are located on sex chromosomes have a distinct pattern of inheritance.
- The expression of certain genes may be influenced by other genes and by environmental factors.

17.3 Genetics and Society

- Deliberate selection of particular traits can lead to the development of new breeds of plants and animals.
- The pattern of inheritance of human traits is usually studied through the analysis of pedigrees.
- Genetic screening and diagnosis can determine whether an individual carries genes for a particular genetic condition.

Common Misconceptions

- Some students may incorrectly believe that different breeds of dogs belong to different species. Remind them that only the wolf, *Canis lupus lupus*, belongs to a different species. All breeds of dogs, from toy poodles to Saint Bernards, belong to the same species, *Canis familiaris*.
- After viewing Figure 17.31 on page 613 (pedigree showing the inheritance of hemophilia, an X-linked recessive trait, in the European Royal families), students may believe that all male offspring of a female carrier will have hemophilia. Remind students that only offspring that are either affected or carriers are shown in this pedigree due to space restrictions. In actual fact, male offspring of a female carrier (where the father does not have hemophilia) have a 50 percent chance of inheriting the disease. Have students complete a Punnett square crossing a carrier female (X^HX^h) and a non-affected male (X^HY) to reinforce this point. **Note: In Figure 17.31, Victoria, in the second generation, is incorrectly shown as having hemophilia. She should be a carrier only.**
- It is often said of some specific trait that it "skips a generation." Recessive traits are often not expressed, but it could be many generations before two identical recessive alleles are found together in the same zygote and are therefore expressed in the phenotype of the individual. There are no cases for which a specific trait always skips one generation.
- Students may believe that the dominant form of a trait is better, or is most commonly expressed in a population. However, this is not the case. For example, polydactyly (more than five fingers or toes) is the result of a dominant allele, but very few people exhibit this trait phenotypcially.

Helpful Resources

Books and Journal Articles

- Jenkins, M. *Teach Yourself Genetics*. McGraw-Hill Ryerson: Whitby, ON, 1998.
- Lewis, R. *Human Genetics: Concepts and Applications 6/e*. McGraw-Hill Ryerson: Whitby, ON. 2005.
- Allen, G. "Mendel and modern genetics: the legacy for today." *Endeavour.* June 2003, Volume 27, Issue 2: 62–68.

Web Sites

Web links related to this chapter can be found at **www.albertabiology.ca.** Go to the Online Learning Centre, and log on to the Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities; or to supply answers (ANS) for assessment or handouts. The BLMs are in digital form, stored on the CD that accompanies this Teacher Resource or on the web site at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, BLMs.

Number (Type)
BLM 17.0.1 (HAND) Launch Lab: Coin Toss
BLM 17.0.1A (ANS) Launch Lab: Coin Toss Answer Key
BLM 17.0.2 (HAND) Probability
BLM 17.0.2A (ANS) Probability Answer Key
BLM 17.1.1 (OH) Mendel's Pea Plants
BLM 17.1.2 (HAND) Genetic Terminology
BLM 17.1.3 (OH) Punnett Square
BLM 17.1.4 (OH) Mendel's Monohybrid Crosses
BLM 17.1.5 (HAND) Monohybrid Crosses Worksheet
BLM 17.1.5A (ANS) Monohybrid Crosses Worksheet Answer Key
BLM 17.1.6 (OH) Test Cross
BLM 17.1.7 (HAND) Investigation 17.A: Testing the Law of Segregation

BLM 17.1.7A (ANS) Investigation 17.A: Testing the Law of Segregation Answer Key
BLM 17.1.8 (OH) Mendel's Dihybrid Cross
BLM 17.1.9 (HAND) Dihybrid Crosses Worksheet
BLM 17.1.9A (ANS) Dihybrid Crosses Worksheet Answer Key
BLM 17.1.10 (OH) Incomplete Dominance and Co-dominance
BLM 17.1.11 (HAND) Incomplete Dominance and Co-dominance Worksheet
BLM 17.1.11A (ANS) Incomplete Dominance and Co-dominance Worksheet Answer Key

BLM 17.2.1 (OH) Chromosome Mapping
BLM 17.2.2 (HAND) Chromosome Mapping Worksheet
BLM 17.2.2A (ANS) Chromosome Mapping Worksheet Answer Key
BLM 17.2.3 (HAND) Thought Lab 17.1: Mapping Chromosomes
BLM 17.2.3A (ANS) Thought Lab 17.1: Mapping Chromosomes Answer Key
BLM 17.2.4 (OH) Sex Linked Inheritance: Colour Blindness
BLM 17.2.5 (OH) Multiple Alleles: Blood Type
BLM 17.2.6 (OH) Polygenic Inheritance: Ear Length in Corn
BLM 17.2.7 (HAND) Investigation 17.B: Environmental Influences on Gene Expression
BLM 17.2.7A (ANS) Investigation 17.B: Environmental Influences on Gene Expression Answer Key

BLM 17.3.1 (OH) Pedigree Symbols
BLM 17.3.2 (OH) Pedigree—Autosomal Dominant Traits
BLM 17.3.3 (OH) Pedigree—Autosomal Recessive Traits
BLM 17.3.4 (OH) Pedigree—Sex-linked Recessive Traits
BLM 17.3.5 (HAND) Pedigree Problem Worksheet
BLM 17.3.5A (ANS) Pedigree Problem Worksheet Answer Key
BLM 17.3.6 (HAND) Thought Lab 17.2: Creating a Pedigree
BLM 17.3.6A (ANS) Thought Lab 17.2: Creating a Pedigree Answer Key
BLM 17.3.7 (HAND) Inherited Genetic Diseases
BLM 17.3.8 (HAND) Thought Lab 17.3: Analyzing Pedigrees
BLM 17.3.8A (ANS) Thought Lab 17.3: Analyzing Pedigrees Answer Key

BLM 17.4.1 (HAND) Chapter 17 Test
BLM 17.4.1A (ANS) Chapter 17 Test Answer Key

Using the Chapter 17 Opener

Student Textbook pages 584–585

Teaching Strategies

- Have students read about the selective breeding of the Appaloosa in the Chapter Opener. Ask students to identify other plants and animals that humans have selectively bred throughout history. What characteristics were these organisms bred for? How is a successful selective breeding program carried out? Challenge students to come up with organisms that are being selectively bred today. (For example, non-allergenic guide dogs for the blind, such as the Labradoodle, are being bred to act as assistance dogs for blind individuals who are allergic to dogs.)
- Use the Launch Lab: Coin Toss.
- Start your discussion on genetics by introducing some single gene traits in humans. These traits are discussed in Section 17.3, but this activity will provide your students with concrete examples of how genes control the physical appearance of an organism. For example, have your students fold their hands on their desks and then have them check which thumb is on top (left thumb on top is dominant). Some other examples are attached versus free-hanging ear lobes (free-hanging earlobes is dominant); peaked versus smooth hair line (peaked is dominant); tongue-rolling (ability to roll tongue into a tube is dominant); or second finger shorter than fourth (dominant in males; recessive in females).
- Show pictures of famous celebrities and their biological parents. Have students identify specific traits that they may have inherited from each parent.
- Review the concepts of variation in a population, natural selection, and artificial selection that were introduced in grade 9 science and again in Biology 20. Ask students how these may be related to the inheritance of characteristics.

Chapter Opener Inset Figure

Student Textbook page 585

Discuss this photo as a class and encourage your students to come up with suggestions. In fact, while scientists once thought that there was just one gene controlling eye colour in humans, there are actually three genes that play a role. Two genes on chromosome 15 code for brown and blue eye colour, while the third gene, on chromosome 19, has a blue allele and a green allele. These genes display an order of dominance. The green allele is dominant to the blue allele, but is recessive to the brown allele. Ask students if they can find any holes in this model. For example, while the model explains the presence of brown, green, and blue eyes, it doesn't explain other eye colours, such as hazel, or blended shades, like green-blue. Nor does it explain how eye colour can change with time (all infants initially have blue eyes). Eye colour can change in adults over time as well, and some medications, injuries, and environmental factors can also cause colour changes.

Launch Lab: Coin Toss

Student Textbook page 585

Purpose

The purpose of this activity is to review the concept of probability and how it is used in the study of genetics.

Outcomes

30-C2.3s

Advance Preparation

When to Begin	What to Do
3 of 4 days before	■ Arrange to have a sufficient number of coins available for the class.
1 day before	■ Photocopy **BLM 17.0.2 (HAND) Probability**, if using. ■ Photocopy **BLM 17.0.1 (HAND) Launch Lab: Coin Toss.**

Time Required

30 minutes

Helpful Tips

- Use **BLM 17.0.1 (HAND) Launch Lab: Coin Toss** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 18.0.1A (ANS) Launch Lab: Coin Toss Answer Key.**
- When you toss two coins, you know that there is a 1 out of 2 chance of getting "heads" or "tails" each time you toss the coin. Therefore the probability distribution of the event tossing two coins and both coming up "heads" is 1/4; one coin coming up "heads" and the other coin coming up "tails" 1/2; both coins coming up "tails" is 1/4. There is a 1 in 4 chance that both coins will be "heads," a 1 in 2 chance that one coin will be "tails" and the other "heads," and a 1 in 4 chance that both coins will be "tails."
- Distribute **BLM 17.0.2 (HAND) Probability** to your students. This BLM provides background information on probability for your students, as well as additional questions on probability.
- In this activity, students are to group "head–head" and "head–no head (tail)" into one category called "Heads." They are to group "no head–no head" (or "tail–tail") into a category called "No Heads." This is designed to introduce the idea that one of the traits, "Heads," is dominant while the other trait, "No Heads" is recessive.
- Create a class data-collecting table on the board or overhead transparency. Instruct students how to add their data to the class, as required in Analysis question 3. Emphasize that this larger number of observations is required before the actual results (experimental results) are likely to come close to the theoretical results.
- Have students record their predictions for the results of "Heads" and "No Heads" prior to starting the activity. In this activity, the expected probability of tossing "Heads" is 3/4 or 75 percent, while the probability of tossing "No Heads" is 1/4 or 25 percent.
- Provide clear expectations on acceptable behaviour (e.g., how high students can toss the coins in the air). Establishing clear rules and procedures can reduce the probability of the coins being tossed all over the classroom. You may wish to use small-denomination coins, such as pennies.
- Collect the coins at the end of the activity. You may wish to use these as a prop when introducing monohybrid crosses. For example, you could replace "Heads" and "No Heads" with symbols for specific alleles such as (*T*) for tall pea plants and (*t*) for short pea plants.
- *Expected Results*: In this activity, the expected probability of tossing "head-head and head-no head" is 3/4 or 75% while the probability of tossing "no head - no head" is 1/4 or 25%.
  Sample data for 60 tosses

Results	Prediction "Heads" (Head–Head or Head–No head)	Prediction "No Heads" (No head –No head)	Actual "Heads" (Head–Head or Head–No head)	Actual "No Heads" (No head –No head)
Toss Results			𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 II	𝍸 𝍸 𝍸 III
Total	45	15	42	18

Safety Precautions

Have students wash their hands after handling money.

Answers to Analysis Questions

1. The following is a sample of possible data for this investigation for one group:

Results	Prediction "Heads" (Head–Head or Head–No head)	Prediction "No Heads" (No head –No head)	Actual "Heads" (Head–Head or Head–No head)	Actual "No Heads" (No head –No head)
Toss Results			𝍸 II	III
Total	8	2	7	3

The percent error in the number of "Heads" is

$$\text{percent error} = \left[\frac{\text{observed} - \text{expected}}{\text{expected}}\right] \times 100$$

$$\text{percent error} = \left[\frac{7 - 8}{8}\right] \times 100$$

$$\text{percent error} = \left[\frac{1}{8}\right] \times 100$$

$$\text{percent error} = 12.5\%$$

Note that the negative sign is dropped in this calculation because you cannot have a negative error.

2. Students with a small percent error in their results should state that their results supported their hypothesis. Those with a larger percent error should state that their results did not support their hypothesis.
3. In most cases, the class data will have a much smaller percent error than individual results. However, this may not be the case if some students' predictions matched their actual data.

Assessment Options

- Collect and assess student answers to the Analysis questions or review as a class.
- Collect and assess **BLM 17.0.2 (HAND) Probability**, if using.

17.1 Laying Foundations: Peas, Patterns, and Probabilities

Student Textbook pages 586–598

Section Outcomes

Students will:

- describe the evidence for segregation and the independent assortment of alleles
- compare ratios and probabilities of genotypes and phenotypes for dominant and recessive alleles, incompletely dominant alleles, and co-dominant alleles
- perform an experiment to demonstrate the inheritance of a trait controlled by a single gene
- interpret patterns and trends in data from monohybrid and dihybrid inheritance

Key Terms

selective breeding
true breeding
monohybrid cross
dominant
recessive
complete dominance
law of segregation
genotype
phenotype
homozygous
heterozygous
Punnett square
test cross
dihybrid cross
law of independent assortment
incomplete dominance
co-dominance
chromosome theory of inheritance

Biology Background

- Mendel published the results of his investigation of pea plants in 1866. Noted scientists of the time were not interested in his work, and seemed unable or unwilling to understand it. Not until over thirty years later, in 1900, did several scientists independently "discover" Mendel's work. Mendel's contribution to our understanding of the genetic basis of heredity is all the more noteworthy when one considers the alleles, genes, and chromosomes were not yet discovered. Mendel worked for eight years with pea plants before publishing the results. The pea plants were an excellent choice as they are easy to grow and pollinate (the flowers contain both male and female sex organs), have a short growing season, and have several easily identifiable traits.
- Mendel tested seven different characteristics in his pea experiments. Although he did not know this at the time, each characteristic is determined by genes that lie on a different one of the seven pairs of chromosomes of the pea. Had he selected eight or more characteristics, then at least two genes would be on the same chromosome and linked. Presumably, Mendel did considerable experimentation and observation before publishing his study. How could Mendel know that those seven characteristics would provide the phenotypic ratios that we now understand are produced by the monohybrid and dihybrid crosses that students will learn in this section? Here we have a glimpse of the great intellect and weight of experimentation that led Mendel to know that seven, and not eight, characteristics were what he must use; and all this done in a time when genes and chromosomes were unknown.

Teaching Strategies

- There are many new terms introduced throughout this unit. Have students use root word meaning cards, coloured vocabulary cards, or other strategies you may have already employed to help students with the terminology used in this course. Also try to make real-world connections to the terms whenever possible. For example, connect genotype to genetics and phenotype to physical appearance.
- Use 2 coins or similar disks with the symbols for alleles taped on them to model the probability of inheriting single traits. The coins represent the possible alleles that would be found in the gametes of an individual female or male organism. For example, one coin could have a capital "*R*"

on it to represent the dominant gene that produces round seeds in pea plants, while the other side of the coin could have a lower case "*r*" on it to represent the recessive allele for wrinkled seeds. The other coin could have the same arrangement. Students can "toss" both coins and record the possible allele combinations that could occur in the zygote i.e., *RR*, *Rr*, or *rr*. If the data sample is large enough, students should see that results of their coin tossing activity should come relatively close to Mendel's 3:1 ratio.

- Figure 17.1 on page 586 can be used to springboard a class discussion on selective breading and the wide variety of traits now seen in members of the species *Canis familiaris* as a result of years of selective breeding by humans.
- **BLM 17.1.1 (OH) Mendel's Pea Plants** combines the information from Figure 17.4 and Table 17.1. Photocopy to provide students with a quick reference of the dominant and recessive traits that Mendel studied in pea plants, or use as an overhead teaching tool.
- **BLM 17.1.2 (HAND) Genetics Terminology** is a dictionary style BLM. It provides students with a quick reference to all of the new terms introduced in this chapter.
- **BLM 17.1.3 (OH) Punnett Square** outlines how to use a Punnett square to predict the possible genotypes and phenotypes in one- and two-trait crosses.
- **BLM 17.1.4(OH) Mendel's Monohybrid Crosses** provides overheads of Figures 17.5 and 17.8 to support your discussion of these crosses and their outcomes.
- **BLM 17.1.5 (HAND) Monohybrid Crosses Worksheet** provides students with an opportunity to solve more one-trait cross genetics problems.
- **BLM 17.1.6 (OH) Test Cross** provides an overhead of Figure 17.9 on page 591 of the textbook to facilitate your instruction of this topic.
- Use **BLM 17.1.8 (OH) Mendel's Dihybrid Cross** to illustrate Mendel's cross of true breeding tall pea plants with green pods (*TTGG*) with true breeding short pea plants with yellow pods (*ttgg*). You may want to black out the phenotype ratio at the bottom of the Punnett square and ask students to determine this ratio for the dihybrid cross. **BLM 17.1.9 (HAND) Dihybrid Crosses Worksheet** provides further practice problems for student to complete.
- **BLM 17.1.10 (OH) Incomplete Dominance and Co-dominance** illustrates the different characteristics of traits that show incomplete dominance and co-dominance, and also provides an illustration of the Punnett squares and phenotype ratios that result from monohybrid crosses involving incompletely dominant and co-dominant traits. Practice problems are available on **BLM 17.1.11 (HAND) Incomplete Dominance and Co-dominance Worksheet,** a worksheet-style BLM designed to reinforce these two concepts.

SUPPORTING DIVERSE STUDENT NEEDS

- This chapter introduces students to a number of new terms, such as "homozygous." Employ a number of strategies to help ESL students and other students struggling with the vocabulary understand the root meaning of these terms. For example, have students write down part of this term, "homo," and its root meaning, "means the same," is a clue that both alleles must be the same.
- You may also wish to consider a reading technique such as SQ3R—Survey, Question, Read, Recall, and Review. This is a useful technique for helping students fully absorb written information. This technique helps students create a good mental framework of a subject, into which they can fit facts correctly. It also helps students to set study goals, as well as prompting them to use the review techniques that will help to fix information in their mind.

Answers to Questions for Comprehension

Student Textbook page 587

Q1. Selective breeding is the choosing and breeding of specific plants and animals in order to favour particular physical features or behaviours in their offspring. Examples could include plants bred for climates like Canada's (e.g., Red File Wheat) or animals bred for specific purposes.

Q2. Students will select two from pangenesis (egg and sperm contain particles from all parts of the male and female body that develop into body parts from which they were derived in the offspring), Leeuwenhoek's homunculus (the sperm contains a miniature person), Graaf's egg-containing miniature person, and the notion of blending (offspring are an irreversible blend of characteristics of both parents).

Student Textbook page 588

Q3. A true breeding plant is one that exhibits the same characteristics with each generation. A hybrid plant is the offspring of a cross between two parent organisms that have different inheritable traits. Therefore, the characteristics of the offspring in succeeding generations could be different from those of the parental generation.

Q4. The P generation is the parental generation, the organisms that are originally crossed. The F_1 generation is the first filial generation. It consists of the offspring of the P generation. The F_2 generation is the second filial generation. It consists of the offspring of two organisms from the F_1 generation.

Student Textbook page 589

Q5. A sample response: Individuals have two "factors" for each trait, but their gametes contain only one factor for each trait because the "factors" separate randomly during gamete formation. Students may give the example of a cross between two true breeding pea plants. The F_1 generation will all show the characteristics of the true breeding parent plant carrying the dominant allele. All the F_1 plants have one allele from each parent; the dominant allele is expressed and the recessive one is hidden.

Student Textbook page 590

Q6. The term dominant refers to a characteristic (trait) that is expressed even if the individual is heterozygous for both alleles (dominant and recessive). Recessive refers to a characteristic (trait) that is only expressed if an individual is homozygous for that allele.

Q7. A gene is what determines individual traits, while an allele is one of the different forms of a gene.

Q8. Genotype refers to the combination of alleles for any given trait, while phenotype refers to the outward expression (physical, observable form) of a trait. For example, an individual pea plant with the genotype *RR* would have the phenotype of round seeds.

Q9. Being homozygous for a trait means that an individual has two identical alleles for that trait. Being heterozygous for a trait means that an individual has two different alleles for a trait.

Answers to Practice Problems

Student Textbook page 591

1. Problem

Mendel crossed true breeding plants that had yellow pods with true breeding plants that had green pods. Using the information in Table 17.1, predict and write down the genotypes and phenotypes of the F_1 and F_2 generations. Predict the ratio of F_2 plants with green pods to F_2 plants with yellow pods.

What is Required?

You must determine the genotypes and phenotypes of the F_1 and F_2 generations of a cross between two plants. You must then use your results from the F_2 cross to predict a phenotypic ratio.

What is Given?

Phenotypes of the parental plants:

yellow pods × green pods

The green pod allele (*G*) is dominant and the yellow pod allele (*g*) is recessive.

You know that a true breeding plant is homozygous for a given trait. Therefore, the plant with yellow pods is homozygous recessive (*gg*), and the plant with green pods is homozygous dominant (*GG*).

Plan Your Strategy

Draw a Punnett square to predict the genotypes of the F_1 generation resulting from a cross between *GG* and gg.

Draw another Punnett square using the gametes produced in the F_1 generation to perform a monohybrid cross.

Using your knowledge of the dominance relationship between the *G* and g alleles, predict the phenotype of each genotype. Express the phenotypic results of the F_2 cross as a ratio of outcomes with green pods to outcomes with yellow pods, and reduce the ratio to lowest terms if necessary.

Act on Your Strategy

Step 1

P generation: $gg \times GG$

	G	*G*
g	*Gg*	*Gg*
g	*Gg*	*Gg*

The F_1 generation plants all have a heterozygous genotype of *Gg*. Since the allele for green pods is dominant, all of the F_1 plants will have green pods. The gametes produced by the F_1 plants are *G* and *g*.

Step 2

F_1 cross: $Gg \times Gg$

	G	*g*
G	*GG*	*Gg*
g	*Gg*	*gg*

The F_2 generation plants have three different genotypes: *GG*, *Gg*, and *gg*. Since the allele for green pods is dominant, the *GG* and *Gg* genotypes will both result in a phenotype of green pods, while the *gg* genotype will produce yellow pods.

Step 3

There are three outcomes with green pods and one outcome with yellow pods. Therefore, the ratio of F_2 plants with green pods to F_2 plants with yellow pods is 3:1. This ratio is already in lowest terms.

Check Your Solution

The 3:1 ratio is the same ratio predicted for a second generation cross from true breeding parents.

2. Problem

In one of his experiments, Mendel counted 6022 yellow seeds and 2001 green seeds. Write the genotypes and phenotypes of the plants in all the crosses he did in order to get these results. How well did his data fit the predicted ratios?

What is Required?

You need to determine what crosses would yield the given numbers of each phenotype, and predict the genotypic outcomes of these crosses. You must then calculate the

approximate ratio of the two phenotypes and compare this ratio with the ratio predicted by Mendel.

What is Given?

number of yellow seeds = 6022

number of green seeds = 2001

You know that the yellow seed allele (*Y*) is dominant to the green seed allele (*y*).

Plan Your Strategy

Find the approximate ratio of yellow seeds to green seeds by dividing the number of yellow seeds by the number of green seeds.

Use your knowledge of Mendel's experiments to predict the type of cross that would give this ratio.

Compare Mendel's predicted ratio to the actual ratio calculated from the data.

Act on Your Strategy

Step 1

$$\frac{\text{\# of yellow seeds}}{\text{\# of green seeds}}$$

The ratio of yellow seeds to green seeds is approximately 3:1.

This ratio would result from a cross between true breeding parents of different phenotypes, followed by self-pollination of the F_1 generation, or a monohybrid cross:

Step 2

Parental cross:

	Y	*Y*
y	*Yy*	*Yy*
y	*Yy*	*Yy*

The F_1 generation would all have the genotype *Yy*, and they would all exhibit the yellow seed phenotype. The gametes produced by the F_1 plants would be *Y* and *y*.

F_1 cross:

	Y	*y*
Y	*YY*	*Yy*
y	*Yy*	*yy*

The F_2 generation would display the genotypes *YY*, *Yy*, and *yy* in an approximate ratio of 1:2:1. The ratio of the yellow seed phenotype to the green seed phenotype in the F_2 generation would be 3:1.

Step 3

Since the actual ratio of yellow seeds to green seeds was 3.009:1 and the predicted ratio is 3:1, the data fit the predicted ratio very well.

Investigation 17.A: Testing the Law of Segregation

Student Textbook 592-593

Purpose

The purpose of this lab is to collect evidence and use a Punnett square to explain how stem colour in *Brassica rapa* (Wisconsin Fast Plant™) is inherited.

Outcomes

- 30-C2.1s
- 30-C2.2s
- 30-C2.3s
- 30-C2.4s

Advance Preparation

When to Begin	What to Do
At the beginning of the school year	■ Order Fast Plant™ *Brassica rapa* seeds from Carolina Biology Supply Company 1-800-334-5551 or **http://www.carolina.com**
3 to 4 weeks before	■ Order Fast Plant™ growing chambers or arrange for the other materials required to grow these plants
1 day before	■ Photocopy **BLM 17.1.7 (HAND): Investigation 17A: Testing the Law of Segregation** ■ Photocopy Assessment Checklist 2 Laboratory Report if you are going to have your students do a formal write up of this investigation ■ Ask students to read the investigation the evening before

Materials

- Order the following seed stocks:
  - Parental Female (P_F) **Non-Purple Stem** (Anthocyaninless: recessive gene blocks the expression of purple, red, or pink pigments)
  - Monohybrid Genetics Kit #15-8770 Carolina Biological Supply Company (Students explore Mendelian genetics through growing and pollinating F_1 hybrid plants to produce F_2 seed)
  - Parental Male (P_M) **Purple Stem, Hairy** (High Anthocyanin: dominant expression of purple pigment in stems)
- light potting mix
- plant fertilizer
- cotton swabs or pipe cleaners
- stakes and ties to support plants
- labels
- fluorescent lights
- instructions for growing, tending, pollinating, and harvesting plants

Time Required

- Initial set-up 60 minutes
- Daily checks 15 minutes
- Final analysis and clean-up 60 minutes
- Total duration of investigation, 6 weeks, depending on the growing conditions

Helpful Tips

- Use **BLM 17.1.7 (HAND) Investigation 17.A: Testing the Law of Segregation** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 17.1.7A (ANS) Investigation 17.A: Testing the Law of Segregation Answer Key**.
- Consider photocopying and distributing Assessment Checklist 2 Laboratory Report (See Appendix A) for students to use as a guide if you are asking them to complete a formal lab write-up for this investigation.
- Anthocyanin is a common purple pigment found in brassicas. It is best observed on the hypocotyls (embryonic stem that emerges from the seed) of seedlings that germinate in the presence of light. A single gene in *B. rapa*, anthocyaninless (*anl*), regulates whether or not anthocyanin is expressed. In the homozygous recessive form (*anl/anl*), anthocyanin expression is completely suppressed, and the hypocotyls appear a bright green colour (the Non-Purple Stem phenotype). If the genotype is heterozygous (*ANL/anl*) or homozygous dominant (*ANL/ANL)*, then anthocyanin is expressed, rendering the hypocotyls purple (the Purple Stem phenotype).
- In this investigation, the plant designated the female parental generation (P_F) has green stems—homozygous recessive (*anl/anl*). The F_1 plants all have purple stems and are heterozygous (*ANL/anl*). The male parental generation (P_M) must have been homozygous dominant (*ANL/ANL*).
- Use the Tips for Growing *Brassica* Fast Plants™ as described below.
- Organize students into teams of 4 to reduce the amount of materials required for this investigation. Assign students specific roles for the duration of the investigation. For example, one student could be responsible for the care of the plants and a second student could be the data recorder.
- Have materials organized into kits to save time during the initial set-up.
- *Expected Results:*
  P_F (parental female generation plants) are grown to show students the green stem phenotype.
  You purchase and grow seeds from the F1 generation. The F1 plants all have purple stems and are heterozygous (*anl/ANL*).
  Students can work backwards to predict the phenotype of the male parent (P_M). They are told that the female genotype is homozygous recessive (*anl/anl*). Students see that the phenotype of the F_1 plants is 100% purple stems. Based on that evidence they can predict that the male plant must have had purple stems and, because none of the F_1 show the recessive phenotype, then the genotype of the P_M must have been homozygous dominant (*ANL/ANL*).
  The F_2 generation would result from crossing plants produced from the F_1 (*anl/ANL*). Crossing two heterozygous plants with the genotypes *anl/ANL* × *anl/ANL* should produce plants in a ratio approximately 3 purple stem plants to 1 green stem plant. Remind students that this is only a mathematical prediction and there could be some discrepancies especially if the sample size is small.

Tips for Growing *Brassica* Fast Plants

Laboratory conditions for growing plants will vary from school to school. *Brassica* can be grown relatively easily with plant trays, fluorescent lights, and a light potting mix.

- Once the plants have emerged from the soil, 24-hour continuous fluorescent light is a critical component for growing *Brassica* successfully. *Brassica* will not grow well on a windowsill or under other low light conditions.
- A light potting mixture consisting of one part peat moss and one part vermiculite is better for growing *Brassica* than potting soil or garden soil.
- Fill the plant container with moist potting mix and tamp it slightly. Do not push or pack the mix down into the plant container.
- Add 2 to 3 times as many seeds (4 to 6) to the top of the mix as plants needed at maturity; cover with potting mix and moisten lightly. Place plant trays under 24-hour fluorescent lights.
- The *Brassica* flowers are monoecious, containing both male and female parts. The one group that is doing the P_F cross must remove the anthers from these plants and then pollinate them with pollen from different *Brassica* (not the same) plants.

- If *Brassica* fertilizers such as Osmocote or Peters Professional Fertilizer are to be used, follow the instructions. Osmocote is added prior to planting the seeds. Check potting mix regularly and keep it moist.
- After 5–7 days, thin the plants to the number required by cutting the stems off the unwanted plants with scissors, just above the surface of the potting mix.
- After 7–14 days stake any plants that may fall over with bamboo skewers and twist ties.
- *Brassica* pollen is sticky and the flowers will not self-pollinate. Flowers must be pollinated artificially to produce seeds.
- When two or more plants have open flowers, pollinate them by transferring pollen from the anther of one plant to the stigma of another plant. Use a bee stick (dried bee thorax glued to a toothpick), cotton swab, or a pipe cleaner.
- Continue repeated cross-pollination of all the open flowers for up to 7 days. Pinch off all unopened buds and side shoots when pollination is finished.
- When mature seed pods are present, about 20 days after the last pollination, stop watering and let the plants dry for a week until the seed pods are crisp and brown.
- Cut the plants off and place them in a paper bag. Label the bag *Brassica* F__ seeds, along with the planting, and pollination information. Let the pods fully dry.
- When the pods are crispy dry, staple the bags shut and crush the pods to release the seeds. Pour the contents of the bag onto a tray and remove the large plant pieces. Gently blow on the chaff to separate it from the seeds. Return the seeds to the bag or place in a labelled envelope. Seeds can be stored in envelopes in zippered plastic bags in a refrigerator.

Safety Precautions

- Remind students to wash their hands after handling materials in the laboratory.
- You could discuss the accidental introduction of plants and plant seeds into the environment and invasive species.

Answers to Analysis Questions

1. Students may identify similarities to Mendel's work, such as growing plants, cross pollinating plants, and quantifying the results of their work. Differences might include the fact that they were working over several weeks instead of several years; that Mendel considered 7 traits overall, while they only considered one; and that scientists have a much greater understanding of how traits are inherited today than Mendel did during his studies.

2. Cutting off the new flower buds and shoots will terminate pollination and allow seed development to occur in the flowers already pollinated.

Answers to Conclusions Questions

3. Accept any answers that clearly compare students' hypotheses and results. Sources of error may include mislabelling of plants, mixing up seeds, etc.

4. Student answers will depend on their hypothesis regarding the inheritance of stem colour. Purple stem colour in standard *Brassica* Fast Plants™ is produced by a dominant allele (*ANL*), and non-purple stem colour is produced by the recessive allele (*anl*). "*ANL*" and "*anl*" refer to the anthocyaninless allele. It is likely that students will use the letters "*P*" and "*p*" for these rather than the accepted "*anl*" notations. In this investigation, the predicted phenotype of the male plants (P_M) is purple stem and the genotype of these plants would be homozygous dominant (*ANL/ANL*).

Parental generation:	Parental female (P_F)	×	Parental male (P_M)
Phenotypes	green stem	×	purple stem
Genotype	*anl / anl*	×	*ANL / ANL*
Possible gametes in alleles	*anl* *anl*	×	*ANL* *ANL*

Use the Punnett Square to predict the genotypes of the F_1 generation.

♂ \ ♀	*anl*	*anl*
ANL	*ANL/anl*	*ANL/anl*
ANL	*ANL/anl*	*ANL/anl*

F_1 genotypic ratio: all plants are *ANL/anl*

F_1 phenotypic ratio: all plants have purple stems

F_2 generation

Parental generation:	Parental female (P_F)	×	Parental male (P_M)
Phenotypes	purple stem	×	purple stem
Genotypes	*ANL / anl*	×	*ANL / anl*
Possible gametes in alleles	*ANL* *anl*	×	*ANL* *anl*

Use the Punnett Square to predict the genotypes of the F_2 generation.

♂ \ ♀	*ANL*	*anl*
ANL	*ANL/ANL*	*ANL/anl*
anl	*ANL/anl*	*anl/anl*

F_2 genotypic ratio: 1 *ANL/ANL* :2 *ANL/anl*:1 *anl/anl*

F_2 phenotypic ratio: 3 purple stem:1 green stem

Assessment Options

- Collect and assess students' answers to the Analysis and Conclusions questions.
- Have students complete a formal lab write up.
- Use Assessment Checklist 2 Laboratory Report from Appendix A

Answers to Questions for Comprehension

Student Textbook page 593

Q10. A Punnett square is a tool (technique) that is used to determine the genotypes of the offspring of a cross between two organisms.

Q11. A test cross is a cross between an organism with an unknown genotype and a homozygous recessive organism in order to determine the unknown genotype.

Q12. A possible response: When the two alleles of one gene segregate, this segregation is not influenced by the alleles of other genes.

Student Textbook page 595

Q13. Incomplete dominance is a condition in which neither of two alleles for the same gene completely conceals the presence of the other.

Q14. Sickle cell anemia and familial hypercholesterolemia are two genetic conditions in humans that exhibit incomplete dominance. In sickle cell anemia, red blood cells are deformed, inhibiting their movement through capillaries. In familial hypercholesterolemia, body tissues are unable to remove low-density lipoproteins from the blood, resulting in higher-than-normal blood cholesterol levels.

Q15. Co-dominance involves both alleles being fully expressed. Incomplete dominance also involves both alleles, but one is expressed without completely hiding the presence of the second.

Q16. In roan colouring, two different colours of horse hair are visible. One allele is expressed in one colour and the other allele is expressed in the second colour.

Student Textbook page 596

Q17. During gamete formation, homologous chromosomes segregate, as do alleles. Also during meiosis, the movement of each pair of homologous chromosomes is independent of all the other pairs; alleles, similarly, assort independently.

Answers to Practice Problems

Student Textbook page 596

3. Problem

In zucchini (*Cucurbita pepo*), the allele for yellow-coloured flesh is recessive to the allele for white-coloured flesh. You are a plant breeder and would like to know if any of the white-fleshed zucchini you have are heterozygous for the yellow-fleshed allele. How would you determine this? Describe the procedure you would follow.

What is Required?

You must decide how to determine if any plants displaying the dominant phenotype have a heterozygous genotype.

What is Given?

You know the dominance relationship between the alleles. The allele for white-coloured flesh is dominant and the allele for yellow-coloured flesh is recessive.

You know that the plants in question have dominant phenotypes.

Plan Your Strategy

Think about the types of crosses you have studied. What type of cross is performed to determine the genotype of an individual with dominant phenotype?

Map out the steps you would use to perform such a cross.

Use a Punnett square to predict the results of a cross between a white-coloured zucchini that is homozygous dominant and yellow zucchini that is homozygous recessive. Repeat this procedure for a white-coloured zucchini that is heterozygous for the flesh-colour allele.

State how you would determine the unknown genotype from the results of the Punnett squares.

Act on Your Strategy

Step 1

A test cross is used to determine the genotype of individuals with a dominant phenotype. The individuals of unknown genotype are crossed with individuals having the recessive phenotype. The genotype of the recessive individuals is known, since the recessive phenotype will only appear when two recessive alleles are present.

Step 2

To perform the test cross, you would use a plant with yellow-fleshed zucchini to pollinate the plants having unknown genotypes. You would then observe the flesh colour of the zucchini that developed, and count the number of each phenotype.

Step 3

Test cross:

If the unknown genotype is homozygous:

	W	*W*
w	*Ww*	*Ww*
w	*Ww*	*Ww*

If the unknown genotype is heterozygous:

	W	w
w	Ww	ww
w	Ww	ww

Step 4

You would expect to see all white-fleshed zucchini in the progeny if the unknown genotype is homozygous dominant. If the unknown genotype is heterozygous for the flesh-colour allele, you would expect to see equal numbers of white-fleshed and yellow-fleshed zucchini in progeny from the test cross. You will be able to identify whether your original zucchini were heterozygous or homozygous by comparing your experimental results with the predicted outcomes for homozygous and heterozygous crosses.

Check Your Strategy

The results agree with the predicted results for test crosses.

4. Problem

In tomatoes (*Lycopersicon esculentum*), red fruit (*R*) is dominant to yellow fruit (*r*), and tall (*T*) is dominant to short (*t*). True-breeding tall plants that produced red fruit were crossed with true-breeding short plants that produced yellow fruit.

(a) State the genotype and phenotype of the F_1 generation plants.

(b) List the genotypes of the gametes produced by the F_1 plants.

(c) List the genotypes and phenotypes of the F_2 generation plants. Include the genotypic and phenotypic ratios of the F_2 generation plants.

What is Required?

(a) You must predict the genotype and phenotype of the F_1 plants resulting from a cross between plants that are true-breeding for two different traits.

(b) You need to predict the gametes produced by the F_1 plants.

(c) You must predict the genotypes, phenotypes, genotypic ratios, and phenotypic ratios of the F_2 plants.

What is Given?

Phenotypes of the parental plants:

tall plants with red fruit × short plants with yellow fruit

The tall plant allele (*T*) is dominant and the short plant allele (*t*) is recessive.

The red fruit allele (*R*) is dominant and the yellow fruit allele (*r*) is recessive.

You know that a true breeding plant is homozygous for a given trait. Therefore, the tall plant with red fruit is homozygous dominant for both traits (*TTRR*), and the short plant with yellow fruit is homozygous dominant for both traits (*ttrr*).

Plan Your Strategy

(a) Draw a Punnett square to predict the genotypes of the F_1 generation resulting from a cross between *TTRR* and *ttrr*. The gametes produced by the plant with genotype *TTRR* will be *TR* and *TR*. The gametes produced by the plant with genotype *ttrr* will be *tr* and *tr*. Use your knowledge of the dominance relationships between the alleles to identify the phenotypes of the offspring.

(b) Identify the gametes present in your Punnett square.

(c) Use the gametes identified in (b) to draw another Punnett square to predict the genotypes of the F_2 plants.

Count the number of each genotype and phenotype present, and express as a ratio.

Act on Your Strategy

(a)

	TR	TR
tr	TtRr	TtRr
tr	TtRr	TtRr

All of the F_1 generation plants will have the genotype *TtRr*, and the phenotype of all plants will be tall with red fruit.

(b) The gametes produced by the F_1 plants will be *TR*, *Tr*, *tR* and *tr*.

(c) Step 1

	RT	Rt	rT	rt
RT	RRTT	RRTt	RrTT	RrTt
Rt	RRTt	RRtt	RrTt	Rrtt
rT	RrTT	RrTt	rrTT	rrTt
rt	RrTt	Rrtt	rrTt	rrtt

Step 2

Genotypes of the F_2 plants:

4 *RrTt*

2 *RRTt*

2 *RrTT*

2 *Rrtt*

2 *rrTt*

1 *RRTT*

1 *RRtt*

1 *rrTT*

1 *rrtt*

This gives a ratio of 4:2:2:2:2:1:1:1:1 for the above genotypes.

Phenotypes of the F_2 plants:

9 tall with red fruit

3 short with red fruit

3 tall with yellow fruit

1 short with yellow fruit

This gives a ratio of 9:3:3:1 for tall red: short red: tall yellow: short yellow.

Check Your Solution

The results agree with those predicted for a dihybrid cross between plants that are true-breeding for two different traits.

5. Problem

In mice, black fur (*B*) is dominant to brown fur (*b*), and non-waltzer mice (*N*) are dominant to waltzers (*n*). Two mice that are heterozygous for both traits are crossed. Draw a Punnett square for the F_1 generation, and determine the phenotypic ratio for these offspring.

What is Required?

You must draw a Punnett square and predict the phenotypic ratio for the F_1 generation of a cross between two individuals heterozygous for two different traits.

What is Given?

Both parents have the genotype *BbNn*.

The black fur allele (*B*) is dominant and the brown fur allele (*b*) is recessive.

The non-waltzer allele (*N*) is dominant and the waltzer allele (*n*) is recessive.

Plan Your Strategy

Determine the gametes produced by the parents.

Draw a Punnett square for the cross.

Use the genotypes produced by the cross to determine the phenotypic ratio.

Act on Your Strategy

Step 1

gamete genotypes: *BN, Bn, bN,* and *bn*

Step 2

	BN	*Bn*	*bN*	*bn*
BN	*BBNN*	*BBNn*	*BbNN*	*BbNn*
Bn	*BBNn*	*BBnn*	*BbNn*	*Bbnn*
bN	*BbNN*	*BbNn*	*bbNN*	*bbNn*
bn	*BbNn*	*Bbnn*	*bbNn*	*bbnn*

Step 3

The phenotypic ratio is 9:3:3:1 for black, non-waltzer to black, waltzer to brown, non-waltzer to brown, waltzer mice.

Check Your Solution

The phenotypic ratio agrees with the predicted results for a cross between individuals that are heterozygous for two different traits.

6. Problem

The gene that codes for colour in snapdragons (*Antirrhinum majus*), exhibits incomplete dominance. A true-breeding red snapdragon is crossed with a true-breeding white snapdragon. What is the phenotypic ratio of the F_1 generation? The F_1 offspring are then crossed to produce an F_2 generation. Draw a Punnett square for this generation and determine the phenotypic ratio.

What is Required?

You need to predict the phenotypic ratios of the F_1 and F_2 generations of a cross between true breeding individuals for a trait that exhibits incomplete dominance.

What is Given?

The parental genotypes are *RR* and *rr*.

The red flower allele (*R*) exhibits incomplete dominance over the white flower allele (*r*). This means the heterozygotes (*Rr*) will be pink in colour.

Plan Your Strategy

Draw Punnett squares for the F_1 and F_2 generations.

Use your knowledge of the dominance relationship for flower colour to determine the phenotypes for both generations. Convert the number of each phenotype into a phenotypic ratio.

Act on Your Strategy

Parental Cross

Step 1

	R	R
r	Rr	Rr
r	Rr	Rr

Step 2

The F_1 generation is made up entirely of heterozygotes, or pink snapdragons.

The gametes produced by the F_1 will be *R* and *r*.

F_1 Cross

Step 1

	R	r
R	RR	Rr
r	Rr	rr

Step 2

The phenotypic ratio for the F_2 generation will be 1 red: 2 pink: 1 white.

Check Your Solution

The phenotypic ratios are consistent with predicted ratios for F_1 and F_2 generations of a cross between true-breeding individuals for a trait with incomplete dominance.

7. Problem

Two blue roan horses are bred together. What is the chance that the colt will be white?

What is Required?

You need to predict the phenotypes of the F_1 generation and use the phenotypic ratio to calculate the probability of the white phenotype appearing.

What is Given?

Both parents are blue roans, or heterozygotes for the roan gene. Roans exhibit co-dominance.

blue roan = *RW* = heterozygous

white horse = *WW* = homozygous

(*RR*, homozygous for the roan gene, was believed to be lethal. There is now data to indicate that this is not true.)

Plan Your Strategy

Draw a Punnett square to predict the genotypes of the F_1 generation.

Use the number of each phenotype in the F_1 generation to calculate the probability of the white phenotype appearing.

Act on Your Strategy

Step 1

	R	w
R	RR	RW
w	RW	ww

Step 2

There is a one in four, or 25%, chance that the colt will be white. (If *RR* is lethal, then one in three living offspring of the cross would be white.)

Check Your Strategy

The probability of the colt being white is consistent with the predicted ratio for a co-dominant trait in a cross between heterozygotes.

Section 17.1 Review Answers

Student Textbook page 598

1. Two coins represent the parents and the heads and tails represent the two alleles. A toss of two coins could result in the following four "genotypes": two "heads," a "head" on the first coin and "tail" on the second, a "tail" on the first coin and a "head" on the second, or two "tails." Assuming "heads" to be dominant, then these four "genotypes" would represent the "phenotypes" 3 dominant ("heads") and 1 recessive ("tails").

2. Mendel's experiments were unusual for biology experiments in the 1800s because no one expected a monk in a monastery to be growing thousands of pea plants to study inheritance. He was not a "recognized" scientist at the time he published his work. He chose to study seven characteristics of pea plants that, as it turns out, are located on the 7 pairs of chromosomes (1 gene per chromosome). Chromosomes and gene linkage were unknown at the time. Mendel must have done a great deal of prior research to know which seven characteristics to study.

3. Selective breeding refers to choosing which plants or animals to breed in hopes of obtaining the desired characteristics. True breeding refers to breeding only the plants or animals that produce the trait that is wanted and are known to produce that trait generation after generation.

4. The law of segregation refers to the separation of the genes' alleles on homologous chromosomes during meiosis and the formation of gametes.The alleles segregate randomly and each gamete receives one allele of each gene.

5. By crossing true breeding peas with green pods with true breeding peas with yellow pods and observing the pod colour of the F_1 generation, it is possible to determine which pod colour is dominant. Because the pea plants are true breeding, their genotypes must be *GG* and *gg*. Thus, all the F_1 plants will be *Gg* and exhibit the dominant phenotype. If all the F_1 plants have green pods, green pods are dominant and yellow pods are recessive. The reverse is true if all the F_1 plants have yellow pods.

6. (a) The genotype for the F_1 generation is *IiAa*. The phenotype is inflated pods with axial flowers.

(b) F_2 genotypes and phenotypes are determined by a 4x4 Punnett square by placing the F_1 gametes *IA, Ia, iA,* and *ia* across the top of the square, and these same gametes on the left side of the square.

The genotypes and ratios of the F_2 are: 4/16 *IiAa*, 2/16 *IiAA*, 2/16 *Iiaa*, 2/16 *IIAa*, 2/16 *iiAa*, 1/16 *IIAA*, 1/16 *IIaa*, 1/16 *iiAA*, and 1/16 *iiaa*. The phenotypes and ratios of the F_2 are: 9/16 inflated pod shape and axial flower position, 3/16 inflated pod shape and terminal flower position, 3/16 constricted pod shape and axial flower position, and 1/16 constricted pod shape and terminal flower position.

(c) The law of independent assortment states that two alleles for one gene segregate independently of the alleles for other genes during meiosis. The experimental data and ratios in part B support this law because they show that the alleles I and i are sorted independently from alleles A and a, as can be seen in the nine different possible genotypes. .

7. Fruit flies—predicted phenotypes for wing length and body colour for 256 offspring:

(a) Long, gray 9/16 of 256 = 144

(b) Long, black 3/16 of 256 = 48

(c) Short, gray 3/16 of 256 = 48

(d) Short, black 1/16 of 256 = 16

8. (Note: Question should refer to problem 7, not problem 5.)

The fruit fly genotype *LlGg*, when crossed with a llgg genotype, would produce the 1:1:1:1 ratio of long, grey: long, black: short, grey: short, black. The probability of selecting a fruit fly offspring to produce this ratio is as follows: The probability of offspring being long-winged and grey-bodied is 9/16 and the probability of offspring being genotype *LlGg* is 4/16; therefore, the probability of the long-winged and grey-bodied offspring being selected to produce this ratio is 4/9.

9. In problem 8, the genotypes of the parental generation would be *LlGg* × *LlGg*. The results of 139:49:53:15 are close to the expected 148:48:48:16 or the 9:3:3:1 that would be consistent with a heterozygous dihybrid cross of two LlGg fruit flies.

10. Incompletely dominant alleles do not show one trait or the other, but show a "blending" of these characteristics. For example, the flowers of white and red four o'clock plants produce heterozygous pink flowers with the pigment produced by each incompletely dominant allele. Co-dominant alleles are each expressed without "blending" of the trait. For example, roan coat colour in cattle is produced by crossing a cow with a red coat and a bull with a white coat. The roan coat contains intermingled red and white hairs on the coat, rather than a mixing of the red and white pigments in individual hairs. Both alleles are co-dominant and expressed individually in the hair colour. Conversly, if alleles are dominant and recessive, in a heterozygous individual, only the dominant trait will be apparent.

11. (a) The black and white alleles are co-dominant because both black and white feathers are produced in some of the offspring.

(b) No, the ratios of characteristics among the offspring do not follow the pattern you would expect because seven offspring is too small a sample to produce the expected ratio of 1 black:2 speckled:1white. To draw conclusions about the inheritance of this trait, one would need to produce a larger number of offspring.

12. During gamete formation, homologous chromosomes segregate, as do alleles. Also during meiosis, the movement of each pair of homologous chromosomes is independent of all the other pairs; alleles, similarly, assort independently. This discovery by Walter Sutton led to the chromosome theory of inheritance.

17.2 Extending Mendel's Laws: More Patterns and Probabilities

Student Textbook pages 599–609

Section Outcomes

Students will:

- explain inheritance patterns for genes on the same chromosome
- analyze crossing over data and create a chromosome map for genes on a single chromosome
- describe inheritance patterns for sex-linked genes
- compare ratios and probabilities of genotypes and phenotypes for multiple alleles and for polygenic traits
- design and perform an experiment to investigate the influence of environmental variables on the expression of genetic information in an individual

Key Terms

linked genes
crossing over
chromosome mapping
map unit

recombinant types
parental type
recombination frequency
sex-linked traits
Barr body
multiple alleles
order of dominance
continuous traits
polygenic traits

Biology Background

- Colour blind individuals are unable to perceive or distinguish between various colours. Colour blindness is most frequently an inherited condition; however, colour blindness can also result from injury to the optic nerve, retina, and certain regions of the brain. Through injury, it is possible to become colour blind in certain parts of the field of vision, but not in others. Acquired colour blindness may also be reversible in some cases. This is never the case in inherited colour blindness. There are three types of inherited colour blindness: monochromacy, dichromacy, and anomalous trichromacy. Normally, the retinal cones (light sensitive cells in the eyes) have three different pigments, each of which absorbs different wavelengths of light. Monochromatic individuals are unable to distinguish any colours due to an absence of two or all of these pigments. Dichromatic individuals generally have trouble distinguishing between two colours due to the absence of one of the cone pigments. Individuals experiencing anomalous trichromacy have all three pigments, although the absorption of one or more is impaired. Both dichromacy, and anomalous trichromacy may show X-linked inheritance. In Canada, about 10 % of males and 0.5% of females have some sort of colour blindness.
- Traits that are purely polygenic (traits that are determined by more than one gene) are actually rare in nature. Instead, most polygenic traits are actually "multifactoral traits," traits that are determined by interactions between the environment and a gene or genes. Some examples of multifactoral traits in humans include eye colour, height, fingerprint pattern, body weight, and heart health. For example, a number of genes, as well as environmental factors, such as diet and overall health, influence height.

Teaching Strategies

- Discussion of Thomas Morgan's "fly room" experiments with *Drosophila melanogaster* provides an excellent opportunity to remind students that data that fail to support hypotheses are just as helpful as supportive data. In fact, Morgan won the Nobel Prize as a result of discoveries that arose as a consequence of just such data.
- Encourage students to recreate Morgan's experiment by completing the Biology File: Try This on page 601 of the textbook. By crossing a male and a female from the F_1 generation of flies, just as Morgan and his team did, students will gain an increased understanding of sex-linked inheritance.
- **BLM 17.0.2 (HAND) Probability** provides information on Pascal's triangle. Used together with Figure 17.24, this BLM will help students understand the phenotypic ratios of polygenic traits.
- **BLM 17.2.1 (OH) Chromosome Mapping** and **BLM 17.2.2 (HAND) Chromosome Mapping Worksheet** are designed to support your instruction of chromosome mapping. Use the worksheet as a formative assessment tool, or as a way for students to evaluate their own understanding of this concept.
- **BLM 17.2.4 (OH) Sex Linked Inheritance: Colour Blindness, BLM 17.2.5 (OH) Multiple Alleles: Blood Type**, and **BLM 17.2.6 (OH) Polygenic Inheritance: Ear Length in Corn** provide overheads of the figures in the text that illustrate these concepts.

Answers to Questions for Comprehension

Student Textbook page 601

Q18. The chromosome theory of inheritance states that genes are located on chromosomes, and chromosomes provide the basis for the segregation and independent assortment of genes. The gene-chromosome theory amends the chromosome theory of inheritance and states that genes exist at specific sites arranged in a linear manner along chromosomes.

Q19. Chromosome mapping is a process in which the concept of crossing over is used to determine the relative positions of genes on a chromosome.

Q20. A map unit is defined as the distance between points on a chromosome where a crossover is likely to occur in one percent of all meiotic events.

Q21. Recombinant types are organisms that have a different combination of linked gene alleles than their parents do. Parental types are organisms that have chromosomes that are identical to those of the P generation (linked gene alleles are the same as those of their parents).

Figure 17.17

Student Textbook page 601

Expected ratio of male to female offspring is 1:1.

Biology File: Try This

Student Textbook page 601

red-eyed male

	X^r	Y
X^R	X^RX^R	X^RY
X^r	X^RX^r	X^rY

[↑ Insert "red-eyed female" on left edge of Punnett square]
F_2 Genotype ratio = 1 X^RX^R: 1 X^RX^r: 1 X^RY: 1 X^rY
F_2 Phenotype ratio = 3 red eyes:1 white eyes (2 female red eyes:1 male red eyes:1 male white eyes)

Thought Lab 17.1: Mapping Chromosomes

Student Textbook page 602

Purpose

The purpose of this Thought Lab is to analyze crossover data to create a chromosome map.

Outcome

30–C2.3s

Advance Preparation

When to Begin	What to Do
1 day before	■ Photocopy **BLM 17.2.3 (HAND) Thought Lab 17.1: Mapping Chromosomes.**

Time Required

- 30 minutes for Part A
- 30 minutes for Part B

Helpful Tips

- Use **BLM 17.2.3 (HAND) Thought Lab 17.1: Mapping Chromosomes** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 17.2.3A (ANS) Thought Lab 17.1: Mapping Chromosomes Answer Key**.
- Encourage students to follow the steps outlined in the table in **BLM 17.2.3 (HAND) Thought Lab 17.1: Mapping Chromosomes** (and at the bottom of page 602 of the textbook) to determine map distance.
- You may want to assign Part B to advanced students that show a particular interest in genetics.

Part A—Constructing a Chromosome Map

Answer to Procedure Question

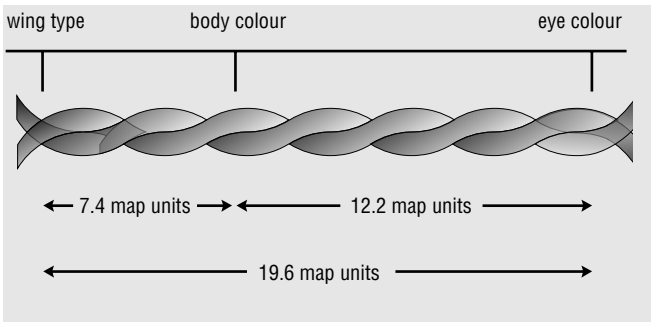
2. Students must first determine the recombination frequency as follows:

Recombination frequency =

$$\frac{\text{number of recombinant types}}{\text{total number of offspring}} \times 100\%$$

$$= \frac{96 + 100}{1000} \times 100\%$$

$$= 19.6\%$$



Answers to Analysis Questions

1. Either no crossover occurred or a double crossover occurred, returning the linked genes back to the same chromosome.

2. Most students will realize that linkage data could not be used to map human chromosomes because humans do not reproduce very quickly or produce a high number of offspring, features that are required for linkage analysis.

Part B—Using Linked Gene Notation

Answers to Procedure Questions

1. (a) Recombination frequency =

$$\frac{\text{number of recombinant types}}{\text{total number of offspring}} \times 100\%$$

$$= \frac{115 + 105}{1000} \times 100\%$$

$$= 22\%$$

The map distance between genes of leg length and eye colour is 22 map units.

(b) Recombination frequency =

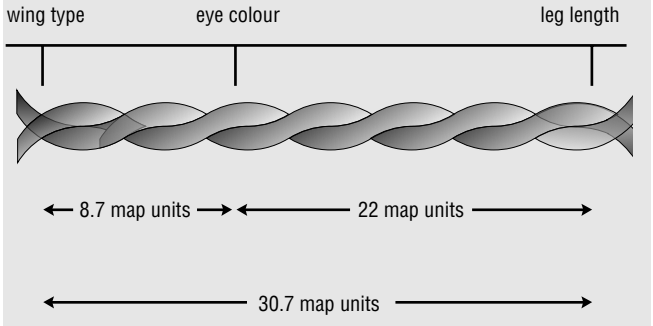
$$\frac{\text{number of recombinant types}}{\text{total number of offspring}} \times 100\%$$

$$= \frac{154 + 153}{1000} \times 100\%$$

$$= 30.7\%$$

The map distance between genes of leg length and wing type is 30.7 map units.

(c) The map distance between genes of eye colour and wing type is 8.7 map units.



Answer to Analysis Question

1. Accept any well-reasoned answer.

Assessment Options

- Collect student answers to Procedure and Analysis questions.

Figure 17.18

Student Textbook page 603

If a student can see the hidden number, his or her genotype is X^CX^C, X^CX^c, or X^CY. If a student can't see the hidden number, his or her genotype may be either X^cX^c, or X^cY; however, not all cases of colour blindness are X-linked.

Figure 17.19 (B)

Student Textbook page 603

Yes, a man with normal vision can have a colour blind male child if the child's mother has the genotype X^CX^c or X^cX^c.

Answers to Practice Problems

Student Textbook page 603

8. Problem

A woman who has normal vision and the heterozygous genotype X^CX^c marries a man who is colour-blind (X^cY). What is the expected ratio of genotypes and phenotypes among their children?

What is Required?

You must determine the ratio of genotypes and phenotypes in the F_1 generation.

What is Given?

The genotypes of the parents are X^CX^c and X^cY. Colour blindness is an X-linked trait.

The allele for normal vision (X^C) is dominant and the allele for colour blindness (X^c) is recessive.

Plan Your Strategy

Draw a Punnett square to predict the genotypes of the F_1 generation.

Use your knowledge of the dominance relationship in the colour blindness trait to determine the phenotype for each genotype, and convert to a ratio.

Act on Your Strategy

Step 1

	X^C	X^c
X^c	X^CX^c	X^cX^c
Y	X^CY	X^cY

Step 2

The genotypic ratio in the F1 generation is 1:1:1:1.

The phenotypic ratio is 1 normal vision: 1 colour blind.

Check Your Strategy

The genotype and phenotypic ratios match those predicted for a cross between a female who is heterozygous and a male who is hemizygous for a recessive X-linked trait. (Hemizygous means that the individual has only one allele for the trait.)

9. Problem

Suppose that you have one wild-type female fly and one white-eyed male fly. What steps would you follow to produce a white-eyed female fly? Illustrate your steps with Punnett squares.

What is Required?

You need to explain how to produce a white-eyed female fly.

What is Given?

The parents are a wild-type female and a white-eyed male.

The trait for eye colour is X-linked and recessive.

The allele for the wild type, or red eyes, (R) is dominant and the allele for white eyes (r) is recessive.

Plan Your Strategy

Determine the possible genotypes of the male and the female.

Draw Punnett squares to predict the results of all possible combinations of genotypes.

Decide whether further crosses are necessary to produce the desired phenotype.

Act on Your Strategy

Step 1

The genotype for the male must be X^rY.

The genotype of the female could be X^RX^R or X^RX^r.

Step 2

If the female fly is homozygous for the eye colour trait:

	X^R	X^R
X^r	X^RX^r	X^RX^r
Y	X^RY	X^RY

If the female fly is heterozygous for the eye colour trait:

	X^R	X^r
X^r	X^RX^r	X^rX^r
Y	X^RY	X^rY

Step 3

If the parent female is heterozygous for the eye colour trait, your first cross will produce a female with white eyes. If the parent female is homozygous for the eye colour trait, you will need to take one of the F_1 females produced by the first cross and mate her with the white-eyed male, which will give the same results as the second cross shown above.

Check Your Solution

You demonstrated a cross that will produce a white-eyed female fly.

10. Problem

In a species of dog, a mutant gene that causes deafness is found on the Y chromosome. Draw a Punnett square to show the outcomes of a cross between

(a) a male dog whose father is deaf and a female dog whose father is not deaf

(b) a female dog whose father is deaf and a male dog whose father is not deaf

What is Required?

You must predict the outcomes of two crosses involving a Y-linked trait.

What is Given?

The mutant gene for deafness is found on the Y chromosome.

normal hearing = Y^D

deaf = Y^d

(a) The male's father is deaf and the female's father is not deaf.

(b) The female's father is deaf and the male's father is not deaf.

Plan Your Strategy

Determine the phenotypes and genotypes of the male and female for each case.

Complete a Punnett square for each cross.

Act on Your Strategy

(a) Step 1

Since the trait is only carried on the Y chromosome, the male must be deaf and the female must have normal hearing.

The male must have the genotype XY^d, and the female must have the genotype XX.

Step 2

	X	X
X	XX	XX
Y^d	XY^d	XY^d

All male offspring will be deaf, and all female offspring will have normal hearing.

(b) Step 1

The female must have normal hearing, since she cannot inherit her father's Y chromosome. The male must have normal hearing.

The male must have the genotype XY^D, and the female must have the genotype XX.

Step 2

	X	X
X	XX	XX
Y^D	XY^D	XY^D

All offspring will have normal hearing.

Check Your Solution

The outcome is logical for a trait that is found on the Y chromosome, which is only passed from male to male.

Figure 17.20

Student Textbook page 604

It is not surprising that male tortoiseshell cats are rare. The tortoiseshell pattern occurs due to inactivation of alternate X chromosomes. Thus, for a male cat to be a tortoiseshell, it must have two X chromosomes (*XXY*), a condition analogous to Klinefetter syndrome in human males, which is a rare genetic occurrence.

Answers to Questions for Comprehension

Student Textbook page 604

Q22. Traits that are controlled by genes on either the X or Y chromosome are called sex-linked traits.

Q23. In every female somatic cell, one of the X chromosomes is randomly inactivated. The inactive X chromosome is condensed tightly into a structure known as a Barr body. This ensures that only one allele of each gene carried on the X chromosome is expressed in each cell.

Q24. A visible effect of the inactivation of one X chromosome is the tortoiseshell coat colour in cats. The tortoiseshell coat colour is the result of a random distribution of orange and black patches. The gene that codes for coat colour (orange or black) is located on the X chromosome. A tortoiseshell cat is heterozygous for the coat colour allele. That is, one X chromosome carries the allele for black fur, and the other X chromosome carries the allele for orange fur. At an early stage of the cat's embryonic development, one X chromosome in each cell is deactivated. The descendants of these cells have the same inactive X as their parent cells. When the kitten is

born, patches of orange show collections of cells in which the X chromosome that is carrying the black allele is deactivated, and patches of black show collections of cells in which the X chromosome that is carrying the orange allele is deactivated.

Student Textbook page 605

Q25. A gene with more than two alleles is said to have multiple alleles.

Biology File: Try This

Student Textbook page 605

Without variation, natural selection would have nothing on which to act. A population is a group of potentially interbreeding organisms of the same species occupying a certain area. Members of a population vary from one another, and it is this variation which is the raw material on which natural selection operates. In sexually reproducing organisms variation can be the result of genetic recombination—the reallocation of alleles and chromosomes. Recombination results from crossing over during meiosis, the random segregation of chromosomes to gametes during meiotic division, and the random combination of gametes during fertilization. The entire genotype is subject to natural selection since new combinations of alleles may improve the reproductive success of the organism. For polygenic traits, the most favourable combination may occur when the right alleles group by recombination at a particular time.

Answers to Practice Problems

Student Textbook page 606

11. Problem

If a man has type AB blood and a woman has type A blood, what possible blood types could their children have?

What is Required?

You need to determine the possible blood types of the children.

What is Given?

The man has type AB blood.

The woman has type A blood.

The I^A allele and the I^B allele are co-dominant and the i allele is recessive.

Plan Your Strategy

Determine the possible genotypes of the man and the woman.

Make Punnett squares for all the possible combinations of parental genotypes to determine the genotypes and phenotypes of the children.

Act on Your Strategy

Step 1

The man must have the genotype I^AI^B.

The woman could have genotype I^AI^A or I^Ai.

Step 2

If the woman has the genotype I^AI^A:

	I^A	I^A
I^A	I^AI^A	I^AI^A
I^B	I^AI^B	I^AI^B

If the woman has the genotype I^Ai:

	I^A	i
I^A	I^AI^A	I^Ai
I^B	I^AI^B	I^Bi

The children could have blood type A, AB, or B.

Check Your Solution

The children must all receive either an I^A or an I^B allele from their father, and an I^A or an i allele from their mother. The predicted blood types are consistent with this information.

12. Problem

In one family, all three siblings have type B blood.

(a) Use Punnett squares to show how two different sets of parent genotypes could produce this result.

(b) Which of the two sets of potential parents in your answer to (a) is more likely to be the parents of these siblings?

What is Required?

(a) You need to identify parental genotypes that would produce children with type B blood.

(b) Decide which cross is more likely to produce three type B children.

What is Given?

All three children have type B blood.

At least two sets of parental genotypes will give this outcome.

The I^A allele and the I^B allele are co-dominant and the i allele is recessive.

Plan Your Strategy

(a) Determine two possible combinations of parental genotypes which could produce offspring with type B

blood. (There are more than two possibilities.) Draw Punnett squares for each combination.

(b) Find the probability of having three children with type B blood for each combination of parental genotypes.

Act on Your Strategy

(a) **Note:** All possible combinations are shown here, but only two are required.

(i) If both parents are homozygous for the I^B allele:

	I^B	I^B
I^B	I^BI^B	I^BI^B
I^B	I^BI^B	I^BI^B

There is a 100% chance that a child will have type B blood.

(ii) If both parents are heterozygous for the I^B allele (I^Bi):

	I^B	i
I^B	I^BI^B	I^Bi
i	I^Bi	ii

There is a three in four, or 75%, chance that a child will have type B blood.

(iii) If both parents are type AB:

	I^B	I^B
I^A	I^BI^B	I^BI^B
i	I^Bi	I^Bi

There is a one in four, or 25%, chance that a child will have type B blood.

(iv) If one parent is homozygous for the I^B allele and the other is heterozygous (I^Bi):

	I^B	I^B
I^B	I^BI^B	I^BI^B
i	I^Bi	I^Bi

There is a 100% chance that a child will have type B blood.

(v) If one parent is homozygous for the I^B allele and the other is blood type AB:

	I^B	I^B
I^A	I^AI^B	I^AI^B
I^B	I^BI^B	I^BI^B

There is a one in two, or 50%, chance that a child will have type B blood.

(vi) If one parent is homozygous for the I^B allele and the other is blood type O (ii):

	I^B	I^B
i	I^Bi	I^Bi
i	I^Bi	I^Bi

There is a 100% chance that a child will have type B blood.

(vii) If one parent is homozygous for the I^B allele and the other is heterozygous for the I^A allele (I^Ai):

	I^B	I^B
I^A	I^AI^B	I^AI^B
i	I^Bi	I^Bi

There is a one in two, or 50%, chance that a child will have type B blood.

(viii) If one parent is heterozygous for the I^B allele (I^Bi) and the other is blood type AB:

	I^B	i
I^A	I^AI^B	I^Ai
I^B	I^BI^B	I^Bi

There is a one in two, or 50%, chance that a child will have type B blood.

(ix) If one parent is heterozygous for the I^B allele (I^Bi) and the other is blood type O (ii):

	I^B	i
i	I^Bi	ii
i	I^Bi	ii

There is a one in two, or 50%, chance that a child will have type B blood.

(x) If one parent is heterozygous for the I^B allele (I^Bi) and the other is heterozygous for the I^A allele (I^Ai):

	I^B	i
I^A	I^AI^B	I^Ai
i	I^Bi	ii

There is a one in four, or 25%, chance that a child will have type B blood.

(b) To determine the probability of all three children having type B blood, you must multiply the probability of one child having type B blood by the probability of each other child having type B blood (i.e. $0.5 \times 0.5 \times 0.5 = 0.5^3 = 0.125$ or 12.5%).

For crosses (i), (iv), and (vi) above, the probability of all three children having type B blood is:

$1.00 \times 1.00 \times 1.00 = 1.00$ or 100%

For cross (ii), the probability of all three children having type B blood is:

$0.75 \times 0.75 \times 0.75 = 0.4218$ or approximatly 42 %

For crosses (v), (vii), (viii), and (ix), the probability of all three children having type B blood is:

$0.5 \times 0.5 \times 0.5 = 0.125$ or 12.5%

For crosses (iii) and (x), the probability of all three children having type B blood is:

$0.25 \times 0.25 \times 0.25 = 0.15625$ of approximately 1.6%

The most likely sets of parents are:

$I^BI^B \times I^BI^B$

$I^BI^B \times I^Bi$

$I^BI^B \times ii$

Check Your Solution

It seems reasonable that a cross including at least one parent with the genotype I^BI^B would be most likely to result in three children with type B blood, particularly when the other parent contributes either I^B or i alleles.

13. Problem

A couple just brought home a new baby from the hospital. They begin to believe that the hospital switched babies, and the baby they brought home is not theirs. They check the hospital records and find that the man's blood type is B, the woman's blood type is AB, and the baby's blood type is O. Could the baby be theirs?

What is Required?

Determine whether blood type O is among the possible outcomes of a cross between an individual with type B blood and an individual with type AB blood.

What is Given?

The man's blood type is B.

The woman's blood type is AB.

The baby's blood type is O.

The I^A allele and the I^B allele are co-dominant and the i allele is recessive.

Plan Your Strategy

Determine the possible genotypes of the man and the woman.

Make Punnett squares for all the possible combinations of genotypes.

Decide whether any of the predicted genotypes will give a phenotype of O.

Act on Your Strategy

Step 1

The woman's genotype must be I^AI^B.

The man's genotype could be I^BI^B or I^Bi.

Step 2

If the man's genotype is I^BI^B:

	I^A	I^B
I^B	I^AI^B	I^AI^B
I^B	I^BI^B	I^BI^B

If the man's genotype is I^Bi:

	I^A	I^B
I^B	I^AI^B	I^BI^B
i	I^Ai	I^Bi

Step 3

Neither of these crosses produces an outcome of ii, or type O blood. The baby could not possibly belong to this couple.

Check Your Solution

In order to produce a genotype of *ii*, one *i* allele would have to come from each parent. Since the mother contributes an I^A allele and an I^B allele, she cannot contribute an *i* allele, and thus cannot give birth to a baby with type O blood.

14. Problem

A chinchilla rabbit with genotype $c^{ch}c^h$ is crossed with a Himalayan rabbit with genotype c^hc. What is the expected ratio of phenotypes among the offspring of this cross?

What is Required?

You must predict the phenotypic ratio.

What is Given?

The genotypes of the parents are $c^{ch}c^h$ and c^hc.

The chinchilla coat allele (c^{ch}) is dominant to the Himalayan coat allele (c^h) and the albino coat allele (c).

The Himalayan coat allele (c^h) is dominant to the albino coat allele (c).

Plan Your Strategy

Draw a Punnett square for the cross to predict the genotypes in the offspring.

Use your knowledge of the dominance relationships among the alleles to determine the phenotype of each genotype.

Convert the number of each phenotype into a ratio. Reduce to lowest terms if necessary.

Act on Your Strategy

Step 1

	c^{ch}	c^h
c^h	$c^{ch}c^h$	c^hc^h
c	$c^{ch}c$	c^hc

Step 2

Since the chinchilla allele is dominant to the Himalayan and albino alleles, the genotypes c^{ch} c^h and $c^{ch}c$ will both display the chinchilla coat phenotype. Since the Himalayan allele is dominant to the albino allele, the genotypes c^h c^h and c^hc will both display the Himalayan coat phenotype.

Step 3

There will be two rabbits with chinchilla coats for every two rabbits with Himalayan coats. Reduced to lowest terms, the phenotypic ratio will be 1 chinchilla: 1 Himalayan.

Check Your Solution

The outcome seems reasonable since the alleles contributed by the parents include one c^{ch} allele, which is dominant to the other alleles present, and two c^h alleles, which are dominant to the remaining *c* allele.

15. Problem

Some of the offspring of a chinchilla rabbit and a Himalayan rabbit are albino. What must be the genotypes of the parent rabbits?

What is Required?

Determine the genotypes of the parents.

What is Given?

The phenotypes of the parents are chinchilla and Himalayan.

Some of the offspring have the albino phenotype.

The chinchilla coat allele (c^{ch}) is dominant to the Himalayan coat allele (c^h) and the albino coat allele (c).

The Himalayan coat allele (c^h) is dominant to the albino coat allele (c).

Plan Your Strategy

Determine the possible genotypes of the parents.

Look for the combination in which each parent will contribute a *c* allele, resulting in the genotype *cc* (the albino phenotype).

Make a Punnett square to predict the outcomes of this cross.

Act on Your Strategy

Step 1

The chinchilla rabbit could have the genotype $c^{ch}c^{ch}$, $c^{ch}c^h$, or $c^{ch}c$.

The Himalayan rabbit could have the genotype c^hc^h or c^hc.

Step 2

In order for each parent to contribute a *c* allele, the chinchilla rabbit must have a genotype of $c^{ch}c$, and the Himalayan rabbit must have a genotype of c^hc.

Step 3

	c^{ch}	c
c^h	$c^{ch}c^h$	c^hc
c	$c^{ch}c$	cc

Check Your Solution

A cross between a chinchilla rabbit with genotype $c^{ch}c$ and a Himalayan rabbit with genotype c^hc will produce chinchilla, Himalayan, and albino offspring in a ratio of 2:1:1.

16. Problem

Could a mating between a chinchilla rabbit and an albino rabbit produce a Himalayan rabbit? Explain your reasoning, with reference to the genotypes and phenotypes of the parents and possible offspring.

What is Required?

Determine whether the Himalayan phenotype could appear in a cross between a chinchilla phenotype and an albino phenotype.

Plan Your Strategy

Determine the possible genotypes of the parents.

Make Punnett squares for all the possible combinations of genotypes.

Act on Your Strategy

Step 1

The albino rabbit must have the genotype *cc*.

The chinchilla rabbit could have the genotype $c^{ch}c^{ch}$, $c^{ch}c^{h}$, or $c^{ch}c$.

Step 2

If the chinchilla rabbit has the genotype $c^{ch}c^{ch}$:

	c^{ch}	c^{ch}
c	$c^{ch}c$	$c^{ch}c$
c	$c^{ch}c$	$c^{ch}c$

If the chinchilla rabbit has the genotype $c^{ch}c^{h}$:

	c^{ch}	c^{h}
c	$c^{ch}c$	$c^{h}c$
c	$c^{ch}c$	$c^{h}c$

If the chinchilla rabbit has the genotype $c^{ch}c$:

	c^{ch}	c
c	$c^{ch}c$	cc
c	$c^{ch}c$	cc

It is possible to produce a Himalayan rabbit in a cross between a chinchilla rabbit of genotype $c^{ch}c^{h}$ and an albino rabbit.

Check Your Solution

In order for the cross to produce a Himalayan rabbit, at least one of the parents must contribute a c^{h} allele. Since the albino rabbit must have the genotype *cc*, the c^{h} allele must come from the chinchilla rabbit. Because the c^{h} allele is dominant to the *c* allele, it will override a *c* allele contributed by the albino rabbit. The solution is reasonable.

17. Problem

Four children have the following blood types: A, B, AB, and O. Could these children have the same two biological parents? Explain.

What is Required?

You must determine whether one cross can produce offspring of all four blood types.

What is Given?

The blood types A, B, AB, and O appear in the offspring.

The I^{A} allele and the I^{B} allele are co-dominant and the i allele is recessive.

Plan Your Strategy

Determine the possible genotypes of the offspring.

List the alleles that must be contributed by the parents to produce each child's genotype.

Find a combination of the necessary alleles that will produce the desired phenotypes.

Act on Your Strategy

Step 1

Blood type A could have genotype $I^{A}I^{A}$ or $I^{A}i$.

Blood type B could have genotype $I^{B}I^{B}$ or $I^{B}i$.

Blood type AB must have genotype $I^{A}I^{B}$.

Blood type O must have genotype *ii*.

Step 2

The alleles I^{A}, I^{B}, and *i* must be contributed by the parents.

In order to produce the genotype ii, each parent must contribute one *i* allele.

In order to produce the genotype $I^{A}I^{B}$, one parent must contribute an I^{A} allele and one parent must contribute an I^{B} allele.

Step 3

The parents must, therefore, have the genotypes $I^{A}i$ and $I^{B}i$.

It is possible for children with the blood types A, B, AB, and O to be borne of the same biological parents.

Check Your Solution

A Punnett square shows that a cross between $I^{A}i$ and $I^{B}i$ produces the phenotypes A, B, AB, and O.

	I^{B}	i
I^{A}	$I^{A}I^{B}$	$I^{A}i$
i	$I^{B}i$	ii

Investigation 17.B: Environmental Influences on Gene Expression

Student Textbook page 608

Purpose

Students work cooperatively to design and perform an experiment to demonstrate how an environmental factor could change the expression of genetic information in an organism.

Outcomes

- 30–C2.2s
- 30–C2.3s
- 30–C2.4s

Advance Preparation

When to Begin	What to Do
1 to 2 days before	■ Photocopy **BLM 17.2.7 (HAND) Investigation 17.B: Environmental Influences on Gene Expression.** ■ Photocopy germinating instructions for the type of seed that you have selected (one copy per group). ■ Photocopy Assessment Checklist 1 Designing an Experiment. ■ Photocopy Assessment Checklist 2 Laboratory Report if you are going to have your students do a formal write-up of this activity. ■ Soak the seeds and/or expose them to red light wavelengths to stimulate germination.

Materials

- seeds (20 seeds per group—10 per petri dish)
- 2 petri dishes
- shoe boxes
- paper towels
- labels or marking pen
- 10 mL graduated cylinder
- water
- light source

Time Required

- 45 minutes to design the investigation and start the lab report
- 30 minutes to start the investigation
- 5 minutes per day to check the seedlings
- 30 minutes on the last day to write up the lab report

Helpful Tips

- Use **BLM 17.2.7 (HAND) Investigation 17.B: Environmental Influences on Gene Expression** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 17.2.7A (ANS) Investigation 17.B: Environmental Influences on Gene Expression Answer Key**.
- Consider providing students with copies of Assessment Checklist 1 Designing an Experiment to help guide them through this process. Students will also benefit from a copy of Assessment Checklist 2 Laboratory Report if you require them to complete a formal lab write-up.
- Select seeds that sprout quickly, such as peas or beans.
- Speed up the germination process by soaking the required number of seeds in a beaker of water overnight. Also, exposing the seeds to red wavelengths of light stimulates seed germination.
- Group students into teams of 2 for this activity.
- Consider providing students with the option of using aluminium foil to cover the petri dishes that are to be grown in the dark. This will take up less space in your lab.
- The following is a sample procedure that students might come up with:
  1. Fold a paper towel into "fours" and cut out a circle that fits into the bottom of a petri dish. Place four layers of paper towel into the bottom of the petri dish.
  2. Use the graduated cylinder to add 10–15 mL of tap water to the paper towel. The paper towel should be wet but not flooded. Hopefully students will use the same amount of water (controlled variable).
  3. Add 10 seeds to each petri dish.
  4. Place the lid on the top of the petri dish.
  5. Place one petri dish in the shoe box or use aluminium foil to completely cover one of the petri dishes. Label both petri dishes.
  6. Place the petri dish in the same area (under a grow light for example). This will control other variables such as temperature.
  7. Observe the seeds on a daily basis and record your observations. It is critical that students do not take the seeds out of the shoe box or take the aluminium foil off for extended periods of time.
  8. Remove foil from covered petri dish and expose seedlings to light. Cover seedlings that were exposed to light previously with foil. Observe seedlings on a daily basis and record observations.
- All the time that the seedling is in the dark, it remains pale yellow or nearly white, and its leaves do not expand. When

the seedling reaches the light, stem elongation is suppressed, and chlorophyll synthesis and leaf expansion are stimulated. This is under the control of the phytochrome system. Plants placed in the dark environment do not synthesize chlorophyll, and leaf expansion does not take place.

- Students should be aware that when doing any investigation they should only have one manipulated variable and one responding variable, and that all other variables should be controlled. As well, they should combine all of the data from the class in order to end up with a more reliable data set.
- *Expected Results*
  Seeds germinated in the dark: All the time that the seedling is in the dark it remains pale or nearly white and its leaves do not expand. This is under the control of the phytochrome system. Plants placed in the dark environment do not synthesize chlorophyll and leaf expansion does not take place.
  Seeds germinated in the light: Select seeds that are heterozygous for chlorophyll production. For example, corn or tobacco seedlings can be green (dominant) or albino (recessive). If you ordered F1 seedlings from a scientific supply company that produce a 3:1 green to albino ratio, the expected genotypic ratio is 1GG: 2Gg to 1gg and the expected phenotypic ratio is 3 green seedlings: 1 albino seedling.

Safety Precautions

- Remind students to wash their hands after handling materials in the laboratory.

Answers to Analysis Questions

1. Accept any answer that clearly explains how the results supported or failed to support students' hypotheses.

2. Student answers depend on their experimental design and unexpected experimental errors. However, students should observe that plants placed in the dark environment do not synthesize chlorophyll. They should also observe that the triggering event is reversible (chlorophyll production starts and stops as light conditions change). Thus, all plants will inherit the chlorophyll-producing genes but their expression is regulated by environmental factors (light levels).

3. Students should identify that the amount of water added to the petri dish, the temperature, the number of days that the seedlings were allowed to develop, and the type of seeds that were used were examples of controlled variables. The manipulated variable was the amount of light the plants were exposed to and the responding variable was chlorophyll production. Controlled variables ensure that any change in the responding variable is the result of changing the manipulated variable. Only one variable is changed during the investigation. All other variables remain the same.

Answers to Conclusions Questions

4. A sample student answer: All the time that the seedling is in the dark, it remains pale or nearly white. When the seedling reaches the light, chlorophyll synthesis is stimulated. Plants placed in the dark environment do not synthesize chlorophyll. Thus, chlorophyll-producing genes are not expressed.

5. If all of the variables are controlled, it is unlikely that students would generate an alternative hypothesis. However, if some variables were not controlled for, then students could hypothesize that these variables, for example temperature or the amount of water used, might have influenced the synthesis of chlorophyll. Students should identify that they would repeat the experiment much as above, except with the new parameter (e.g., temperature, amount of water) being the only variable, in order to test their hypothesis.

Answer to Extensions Question

6. Students might predict that a greater understanding of the effect of light on chlorophyll production could improve food production or the quality of food crops. They might even make a connection between ecological disasters, such as oil spills, and the synthesis of chlorophyll. Another possibility would be the impact of major volcanic activity, or an asteroid colliding with Earth, on the ability of plants to synthesize chlorophyll.

Assessment Options

- Use Assessment Checklist 1 Designing an Experiment from Appendix A to assess how the students actually designed their investigation.
- Use Assessment Checklist 2 Laboratory Report from Appendix A if you have asked the students to do a formal write-up of this investigation.

Answers to Questions for Comprehension

Student Textbook page 609

Q26. A trait such as human blood type results from a single gene that has more than two alleles. A continuous (polygenetic) trait, on the other hand, such as ear length in corn, is controlled by many genes.

Q27. A continuous trait is a trait for which the phenotypes vary gradually from one extreme to another.

Q28. Students may suggest environmental factors such as diet (i.e., malnourishment) or teratogens. Accept any reasonable answer.

Section 17.2 Review Answers

Student Textbook page 609

1. In crossing over, non-sister chromatids in a tetrad exchange pieces of chromosomes in prophase I of meiosis. During the study of two traits (genes found on the same chromosome), it was observed that unexpected phenotypic ratios appeared in the next generation. Because the point at which a crossover occurred was between these genes, their alleles were separated onto different chromosomes and, therefore into different gametes. Genes found on the same chromosome are called linked genes because they are expected to be found in the same gamete. With the observation of crossing over, it was determined that genes, as well as chromosomes, could assort independently. It was further determined that any given pair of linked genes would separate with a predictable frequency, and that this frequency varied among different pairs of linked genes. This is because a crossover is more likely to occur between genes that are farther apart on a chromosome than between genes that are closer together.

2. (a) The man is X^CY and the mother is a carrier of the colour blindness allele X^CX^c.

(b) The child is male (X^cY) because males inherit their X chromosome from the mother, and the Y chromosome from the father. In females, one X is inherited from the father and one from the mother. Since the father has normal colour vision his X^C carries the normal gene. Therefore, all daughters will either be homozygous dominant for colour vision (X^CX^C) or heterozygous and carriers like the mother, X^CX^c.

3. No, a person with type AB blood could not have a child with type O blood, because a parent with AB blood type would produce gametes with I^A and I^B alleles, resulting in offspring with type A, B, or AB blood, depending on the blood type of the other parent.

4. She has no chance of getting an agouti rabbit. Agouti rabbits have genotypes *CC*, Cc^{ch}, Cc^h, or *Cc*. Neither the Himalayan rabbit (genotypes c^hc^h or c^hc), nor the albino rabbit (genotype *cc*) will carry the dominant allele *C*.

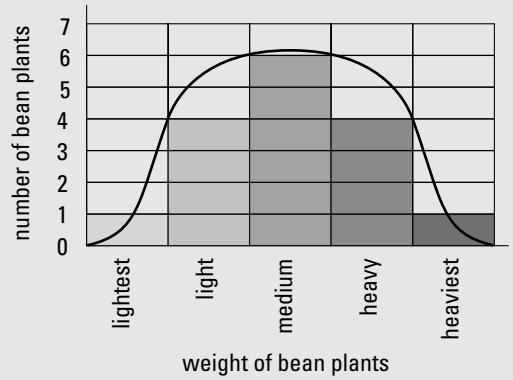
5. (a) You would expect to find five weight classes. Students may use a Punnett square or a bar graph like those shown below to explain why this is the case.

A

AaBb × *AaBb*

♂ \ ♀	*AB*	*Ab*	*aB*	*ab*
AB	*AABB* heaviest	*AABb* heavy	*AaBB* heavy	*AaBb* medium
Ab	*AABb* heavy	*AAbb* medium	*AaBb* medium	*Aabb* light
aB	*AaBB* heavy	*AaBb* medium	*aaBB* medium	*aaBb* light
ab	*AaBb* medium	*Aabb* light	*aaBb* light	*aabb* lightest

B



Phenotypic ration = 1 lightest : 4 light : 6 medium : 4 heavy : 1 heaviest

(b) Environmental factors also determine the range of bean phenotypes, including soil mineral nutrients, water, and sunlight. Additional genetic factors also determine the growth of the beans.

6. Genes are influenced by environmental factors. The cooler outdoor temperatures influence gene expression for fur colour in Siamese cats, and stimulate the production of darker hair colour than is found in indoor cats, which are at a constant warm temperature.

17.3 Genetics and Society

Student Textbook pages 610–617

Section Outcomes

Students will:

- describe ways in which plant and animal breeding programs make use of genetic research
- draw and interpret pedigree charts that show the inheritance of single allele, sex-linked and multiple-allele traits in humans
- design and collaborate on a plan to investigate the inheritance of human traits
- assess the role of genetic counselling and technology in issues that involve society

- evaluate some of the social, ethical, and economic considerations that are involved in the application of genetic research

Key Terms

pedigree
genetic screening
genetic counsellor

Biology Background

- The study of human genetics is complicated by a number of factors. Humans have long life spans and produce very few offspring in comparison with plants or fruit flies. Furthermore, most people do not keep accurate records of their family history. Only in rare cases, such as that of the European royal family, have detailed records been kept for over a century.
- Huntington's disease (HD) is a single-gene condition that is caused by a trinucleotide repeat (CAG) in chromosome 4. It is a degenerative neurological disease that results in loss of muscle control and dementia. It may also affect the personality of those who suffer from it, causing increased aggression, anxiety, depression, or compulsive behaviour. This latter aspect can be especially difficult for families to cope with. The disease afflicts 8 out of every 100 000 people and is one of the first genetic disorders for which an accurate test was devised. Onset is usually after age 35, but may occur at any age. Decline is progressive, and while there is no cure, symptoms can be reduced with medication. As a result, some people with the mutation for Huntington's disease choose not to have children of their own. The most promising prospective treatment and/or cure may lie in a technique called "gene silencing," in which the expression of a specific gene is reduced. This has resulted in the 60% reduction of specific gene expression in mice, but the technique has yet to be used in humans.
- Marfan syndrome is an autosomal dominant condition that is caused by a mutation on the FBN1 gene located on chromosome 15. This gene codes for the expression of a protein called fibrillin-1, which plays an important role in the formation of elastic fibres in the connective tissue. Because connective tissue is found throughout the body, the disorder may affect most body systems. Some common symptoms are unusually long bones, which can lead to abnormal curvature of the spine; eye problems, such as glaucoma; an increased risk of retinal detachment; faulty heart valves; and respiratory problems. Symptoms tend to be mild in young people, but they become increasingly severe over time. The syndrome is also associated with incomplete penetrance, which means that not everyone who carries the mutation for the disease exhibits symptoms. While the syndrome follows an autosomal pattern of inheritance, 25-33% of cases of Marfan syndrome result from de novo (new) mutations in the FBN1 gene.
- Phenylketonuria (PKU) exhibits an autosomal recessive inheritance pattern. In people with PKU, an enzyme that converts phenylalanine to tyrosine is defective or absent due to a mutation on chromosome 15, causing phenylalanine to convert to phenylpyruvic acid, which builds up to toxic levels. Infants with PKU appear healthy at birth. However, if their condition is not diagnosed and treated, they will become severely mentally handicapped within a few months. Newborns are routinely tested for PKU with a blood test that must be performed within days of their birth. If they test positive for the disorder, they are placed on a very restrictive, phenylalanine-free diet. Foods that are high in phenylalanine, such as breast milk, fish, nuts, cheese, and chicken must be removed from the diet. Consumption of starch-rich food, such as rice, potatoes and pasta is also closely monitored. The dietary restrictions can be eased later in life, once the nervous system is more fully developed. In the future, other treatments may be devised for the disease. At present, only gene therapy and the development of an injectable type of PAH, the enzyme that converts phenylalanine to tyrosine, seem promising prospects.
- Genetic counsellors have completed a 2-year master's degree in genetic counselling from an accredited institution. In Canada, McGill University, the University of Toronto, and the University of British Columbia all offer master's degrees in genetic counselling. Genetic counsellors receive extensive training in the following three areas: 1. The science of genetics, including molecular, biochemical, and population genetics; 2. Methods of counselling; and 3. Legal, ethical, and social issues as they are related to the field of genetics.

Teaching Strategies

- Approach the subject of human genetics and genetic diseases somewhat cautiously. You cannot know if a student in the class has a relative or friend with a genetic disorder and is sensitive about the subject.
- Some rural students may be involved in clubs such as 4-H and may be raising their own animals. Discuss the importance of selective breeding of these animals. Others may be actively involved in the family farm and can describe some of the traits in the grain or oil seeds that are being sown each year. Capitalize on their experiences to personalize this section of the course.
- You may have students in your class that are involved in breeding other animals such as dogs, cats, birds, or horses. Others may have pedigree charts for their family pet. Once again, capitalize on their experiences to personal this section of the course.
- The story of Queen Victoria and Prince Albert has been captured in film and in numerous books. Check with your local media distribution centre or librarian to see if they have any videos or other resources that deal with hemophilia in the European royal families.

- Review **BLM 17.3.1 (OH) Pedigree Symbols** with students before they complete Thought Lab 17.2 Creating a Pedigree. This BLM can also be photocopied and distributed to students for easy reference. You may also want to assign the sample problem on page 614 and the practice problems on page 615 before beginning this lab.
- **BLM 17.3.2 (OH): Pedigree – Autosomal Dominant Traits**, **BLM 17.3.3 (OH): Pedigree – Autosomal Recessive Traits**, and **BLM 17.3.4 (OH): Pedigree – Sex-Linked Recessive Traits** provide overheads of the pedigree figures in the textbook, which can be used to review the patterns that typically occur in these different modes of inheritance.
- **BLM 17.3.5 (HAND) Pedigree Problems Worksheet** can be assigned to students who would like additional practice in creating and analyzing pedigrees, or it can be given as an in class quiz.
- **BLM 17.3.7 (HAND): Inherited Genetic Diseases** is an information handout that summarizes a few human genetic diseases. This handout could be used as a starting point for independent research.

Answer to Question for Comprehension

Student Textbook page 611

Q29. Students could name any cereal, fruit, or vegetable crop, as well as any animal that people raise for meat, milk, or hair.

Figure 17.27

Student Textbook page 611

In order to determine the milk productivity of the bull's female offspring, the milk producer would have to have the breeding history of the bull and records of the milk productivity of its recent female ancestors.

Biology File: Web Link

Student Textbook page 611

The Newfoundland Pony is an "all purpose" pony and has many desirable characteristics including strength, stamina, courage, intelligence, obedience, willingness, and common sense. Newfoundland Ponies are hard-workers and easy-keepers. Perhaps the greatest attributes of the Newfoundland Pony are its good temperament, and ability to survive on relatively small amounts of most available grasses and foods. It can also stand harsh winters in relative comfort, mostly due to its thick winter coat.

The ancestors of the Newfoundland Pony arrived with the island's early settlers from the British Isles. These ancestors were primarily Exmoor, Dartmoor, and New Forest ponies, and to a lesser extent, Welsh Mountain, Galloway (extinct), Highland, and Connemara ponies. They were hardy creatures, already well adapted to the harsh climate of the islands of the North Atlantic. Over subsequent centuries, and with little outside influence, the hardiest of these early pony immigrants to Newfoundland interbred and eventually evolved into one common pony type, now recognized as the Newfoundland Pony. Why then are there so few Newfoundland Ponies left?

In 1935, there were 9025 ponies in Newfoundland, and a healthy population existed up to the mid seventies and early eighties. Then the population plummeted!

Perhaps the greatest causes of this decline were:

- Machinery took over the jobs once done by ponies.
- Communities enacted no-roaming laws, limiting breeding and food supply.
- Owners were encouraged to have stallions gelded.
- Thousands of the Newfoundland Ponies were sold to meat processing plants in Quebec, from where the horse meat was sent to Belgium and France for human consumption.

[Sources: **http://www.ansi.okstate.edu/breeds/horses/newfoundland/index.htm**
http://www.newfoundlandpony.com/]

Figure 17.29

Student Textbook page 612

Individual II-2 is heterozygous (one dominant allele and one recessive allele) because two of her children have the recessive phenotype. The only way that these children can have the recessive phenotype is if both the mother and the father have the recessive allele in their genotype.

Answers to Questions for Comprehension

Students Textbook page 612

Q30. Roman numerals are used to indicate different generations. Arabic numerals are used to indicate different individuals within each generation.

Q31. Autosomal inheritance refers to traits—dominant and recessive—that are coded for by genes on autosomes.

Figure 17.30

Student Textbook page 613

You know that individual III-1 is heterozygous because two of his children have the recessive phenotype. In order for the children to have PKU (autosomal recessive trait), they have to inherit a recessive allele from both the father and the mother.

Answers to Questions for Comprehension

Students Textbook page 614

Q32. Autosomal recessive traits tend to skip one or more generations in pedigrees. X-linked recessive traits can skip generations, but some of the females in that generation must be carriers if the trait appears in a later generation. X-linked recessive traits can occur in the male children of females who are carriers or have the trait themselves. Female children may be carriers, but will only have the disease if their father has it and their mother is a carrier or also has it, which is a rare

occurrence. Conversely, autosomal recessive traits appear in both sexes with the same frequency.

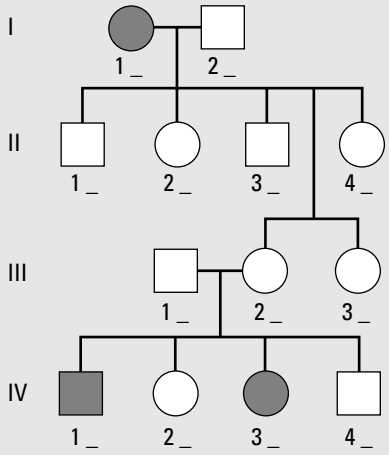
Q33. Yes, a female can have hemophilia if her father has the disease and her mother is a carrier or has the disease.

Answers to Practice Problems

Student Textbook page 615

18. Problem

A curved "hitchhiker's thumb" is recessive to a straight thumb. The following pedigree traces the presence of hitchhiker's thumb in a family. Identify the phenotypes and genotypes of all the people shown in the pedigree. Whose genotypes can you not be certain of?



What is Required?

Identify the genotypes and phenotypes of each individual in the pedigree.

What is Given?

The pedigree is given, and you know the trait is controlled by a recessive allele.

Plan Your Strategy

Identify the phenotypes of all individuals.

Look for an individual with a phenotype that differs from the corresponding phenotype in both parents. All individuals of this phenotype must result from a homozygous recessive genotype.

Write the symbol for the dominant allele below every individual who does not show the trait.

Both parents of the individuals showing the trait must have at least one recessive allele. All the children of a person showing the trait had to receive one recessive allele from this parent.

Act on Your Strategy

Step 1

Each individual represented by a closed symbol has the "hitchhiker's thumb" phenotype, while each individual represented by an open symbol has the straight thumb phenotype.

Step 2

Write a homozygous recessive genotype (*tt*) below the symbol for all the individuals who show the trait (I 1, IV 1, and IV 3).

Step 3

Write the symbol for the one dominant allele (*T*) below all open symbols.

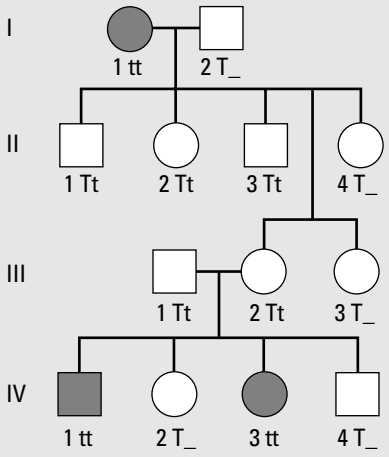
Add a small *t* for individuals II 1, 2, and 3, since they must have received one recessive allele from individual I 1.

Step 4

Individuals III 1 and 2 must also be heterozygous, since they must each donate a recessive allele to individuals IV 1 and IV 3.

Step 5

You cannot determine whether I 2, II 4, III 3, IV 2, and IV 4 are heterozygous or homozygous dominant, since either genotype is possible with the given information.



Check Your Solution

Upon checking the pedigree, all genotypes are correct.

19. Problem

In certain families in Norway, woolly hair (hair that looks like sheep's wool) is passed down through the generations. In order for children to have this trait, at least one of their parents must have woolly hair. How is this trait most likely inherited? Draw a pedigree for a family where one of three children and both parents have woolly hair. Identify the genotypes and phenotypes for each individual in the family. Whose genotype can you not be certain of?

What is Required?

You must determine the method of inheritance of the trait, draw a pedigree, and identify the genotype and phenotype of each family member.

What is Given?

At least one parent must exhibit the trait in order for it to be passed on.

Both parents display the trait.

One of three children exhibits the trait.

Plan Your Strategy

Draw the pedigree.

Look for an individual with a phenotype that differs from the corresponding phenotype in both parents. This phenotype must result from a homozygous recessive genotype.

Write the symbol for the dominant allele below every individual who does not show the homozygous recessive phenotype.

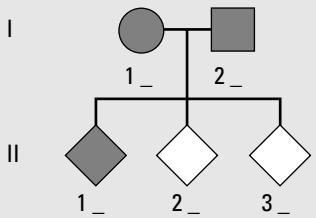
Both parents of individuals who are homozygous recessive must have at least one recessive allele.

Identify genotypes of which you cannot be certain.

Act on Your Strategy

Step 1

Draw the pedigree.



Step 2

Write a homozygous recessive genotype (*hh*) beneath the two children with normal hair, since they differ in phenotype from their parents. The woolly hair allele must be dominant.

Step 3

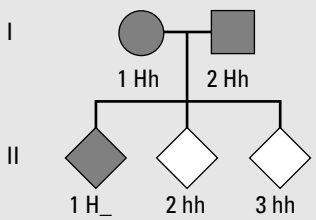
The parents and individual II 1 must carry a dominant allele, since they all display the woolly hair trait.

Step 4

Since both parents must also carry a recessive allele, they must be heterozygous for the trait.

Step 5

You cannot be certain whether the woolly-haired child (II 1) has the genotype *HH* or *Hh*, since either are possible outcomes of a cross between heterozygotes.

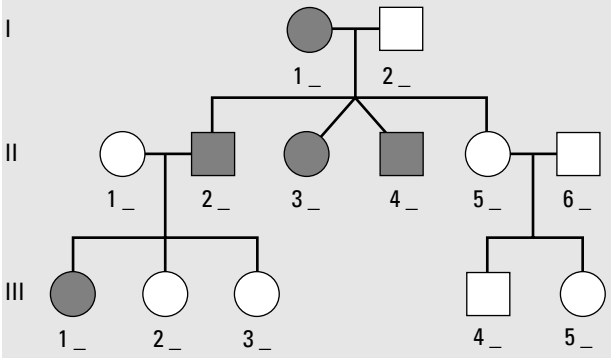


Check Your Solution

Upon checking the pedigree, all genotypes are correct.

20. Problem

This pedigree traces tongue rolling in a family. The ability to roll your tongue is controlled by a dominant allele; people who are homozygous recessive for the trait cannot roll their tongue. Identify the phenotypes and genotypes of all the people shown in this pedigree.



What is Required?

Identify the genotypes and phenotypes of all individuals.

What is Given?

The pedigree is given, and you know the trait is controlled by a dominant allele.

Plan Your Strategy

Identify the phenotypes of all individuals.

Since the trait is controlled by a dominant allele, you can identify homozygous recessive individuals as those who do not exhibit the trait.

Individuals who display the trait must carry at least one dominant allele.

Both parents of individuals who are homozygous recessive must have at least one recessive allele.

State the outcome of known crosses to identify any remaining unknown genotypes.

Act on Your Strategy

Step 1

All individuals represented by filled symbols are tongue-rollers, while all individuals represented by open symbols are non-tongue-rollers.

Step 2

Write a homozygous recessive genotype (*rr*) beneath all individuals who do not show the trait.

Step 3

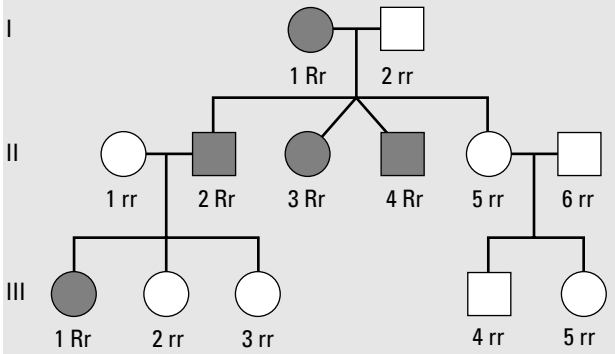
Write an *R* beneath all individuals who do exhibit the trait.

Step 4

Add an *r* to parents who exhibit the trait, but have children who are not tongue-rollers.

Step 5

Individual III 1 is the only one remaining with an uncertain genotype. A cross between *rr* and *Rr* will produce offspring of genotype *rr* or *Rr*. Individual III 1 exhibits the trait, so she must have the genotype *Rr*.

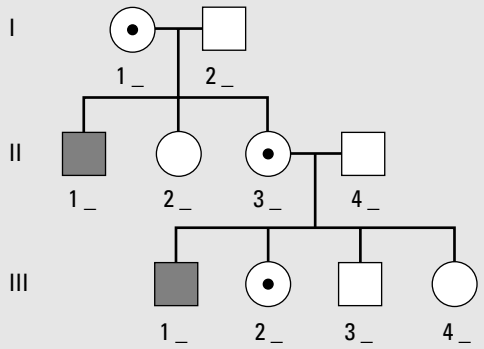


Check Your Solution

Upon checking the pedigree, all genotypes are correct.

21. Problem

Duchenne muscular dystrophy is an X-linked recessive trait. The following pedigree shows the occurrence of this disorder in an extended family. Provide the phenotypes and genotypes of all the individuals in the pedigree.



What is Required?

Identify the phenotypes and genotypes of all individuals.

What is Given?

The pedigree is given, and you know the trait is controlled by a recessive allele on the X chromosome.

Plan Your Strategy

Identify all phenotypes.

Insert a Y allele beneath all male individuals.

Look for an individual with a phenotype that differs from the corresponding phenotype in both parents. This phenotype must result from a homozygous or hemizygous recessive genotype. (**Note:** Hemizygous is a term used to describe males who carry only one copy of genes located on the X chromosome.)

Write the symbol for the dominant allele below every individual who does not exhibit the trait.

Individuals represented by an open symbol with a dot in the centre are known carriers of the X-linked recessive trait.

In a pedigree where carriers are identified by a centre dot, open symbols lacking the centre dot must be homozygous recessive.

Act on Your Strategy

Step 1

All individuals represented by filled symbols suffer from Duchenne muscular dystrophy, while all individuals represented by open symbols do not have the disease.

Step 2

Write a Y beneath each square symbol.

Step 3

Add a recessive allele (X^n, where n represents the Duchenne muscular dystrophy allele) to each individual who exhibits the trait. (If there were any females who displayed the trait, they would have the genotype X^nX^n.)

Step 4

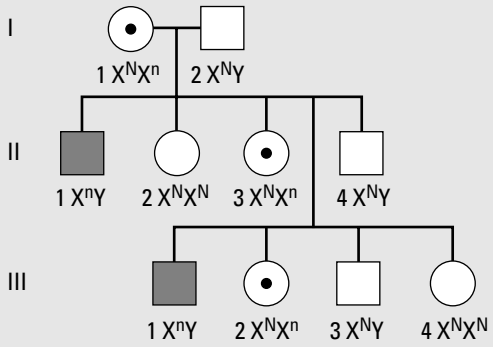
Add a dominant allele (X^N, where N represents the non-diseased allele) to each individual who does not exhibit the trait.

Step 5

Write an X^n beneath each heterozygote identified by a centre dot.

Step 6

Individuals II 2 and III 4 are still of uncertain genotype, but they are represented by open symbols rather than symbols with centre dots, so they must have the genotype X^NX^N.



Check Your Solution

Upon checking the pedigree, all genotypes are correct.

Thought Lab 17.2: Creating a Pedigree

Student Textbook page 615

Purpose

The purposes of this activity are to design a plan to collect data in order to demonstrate human inheritance; to draw and

interpret pedigree charts from human inheritance patterns; and to work cooperatively with a partner to solve problems and communicate information and ideas

Outcomes

- 30–C2.1s
- 30–C2.3s
- 30–C2.4s

Advance Preparation

When to Begin	What to Do
1 day before	■ Photocopy **BLM 17.3.6 (HAND) Thought Lab 17.2: Creating a Pedigree.**

Time Required

- 30 minutes for planning the investigation.
- Several days to gather family data.
- 30 minutes to complete their pedigree.

Helpful Tips

- Use **BLM 17.3.6 (HAND) Thought Lab 17.2: Creating a Pedigree** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 17.3.6A (ANS) Thought Lab 17.2: Creating a Pedigree Answer Key**.
- Review **BLM 17.3.1 (OH) Pedigree Symbols** with students before they complete Thought Lab 17.2 Creating a Pedigree. This BLM can also be photocopied and distributed to students as a reference they can refer to as they create their pedigrees.

Answers to Analysis Questions

1. The answer will depend on the trait selected.
   - hairline: peaked (dominant); straight hairline (recessive)
   - earlobes: unattached (dominant); attached (recessive)
   - thumb: last segment cannot be bent backward (dominant); last segment can be bent backward (recessive)
   - clasped hands: left thumb over right (dominant); right thumb over left (recessive)
   - mid-digit hairs: present (dominant); absent (recessive)
   - tongue rolling: able to roll tongue (dominant); unable to roll tongue (recessive)
   - freckles: freckles present (dominant); no freckles recessive
2. Each pedigree will vary. However, look for consistency in symbols used to construct the pedigree. Symbols should match those shown in Figure 17.28 on page 612.
3. Some data may not fit the predicted patterns. Many human traits are controlled by more than one gene (polygenic) and a distinct phenotype might not be readily apparent.

Assessment Options

- Collect and assess students' pedigree charts and answers to Analysis questions.

Thought Lab 17.3: Analyzing Pedigrees

Student Textbook page 617

Purpose

The purpose of this activity is to interpret a pedigree depicting multiple-allele traits.

Outcomes

- 30–C2.3s

Advance Preparation

When to Begin	What to Do
1 or 2 days before	■ Photocopy **BLM 17.3.8 (HAND) Thought Lab 17.3: Analyzing Pedigrees.**

Materials
■ pen and paper

Time Required

30 minutes

Helpful Tips

- Use **BLM 17.3.8 (HAND) Thought Lab 17.3: Analyzing Pedigrees** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 17.3.8A (ANS) Thought Lab 17.3: Analyzing Pedigrees Answer Key**.
- Review the pedigree symbols used in the lab with students. Blood types A, B, AB, and O are used in addition to traditional pedigree symbols for this multiple-allele pedigree.
- Review how blood types are inherited in humans. Remind students that the allele for type A is dominant to the allele for type O blood; the allele for type B blood is dominant to the allele for type O blood; and the allele for type A blood and the allele for type B blood are co-dominant.
- Have students write on the copy of the pedigree in **BLM 17.3.8 (HAND) Thought Lab 17.3: Analyzing Pedigrees** to discourage them from writing in their textbooks.

Answers to Analysis Questions

1. Individual I4's blood type must be type A because one of her children has type A blood. Individual I6 must have blood type A because his son, II7, inherited the allele for type A blood from him. The son could not have inherited the allele for type A blood from his mother because she has type O blood, and would have the homozygous recessive (*ii*) genotype.
2. The following chart summarizes the phenotype and genotype of each individual in this pedigree chart.

Individual	Phenotype	Genotype(s)	Explanation
I1	type A blood	I^AI^A *or* I^Ai	It is not possible to determine if her phenotype is homozygous dominant or heterozygous.
I2	type AB	I^AI^B	He has had his blood tested – this is the only possible genotype for a person with type AB blood.
I3	type B	I^Bi	He must be heterozygous; otherwise his son would have either type B or type AB blood.
I4	type A	I^AI^A or I^Ai	She must have type A blood because her son has type A blood and could only have inherited that allele from his mother. However, there is insufficient information to determine if the second allele is *A or i*.
I5	type O	*ii*	This is the only genotype for a person with type O blood.
I6	type A	I^Ai	He must be heterozygous for type A blood because one of his children had type A blood —and must have inherited the A allele from him. The second child had type O blood, and must have inherited the recessive *i* allele from him as well as from her mother, who is *ii*.
II1	type A	I^AI^A or I^Ai	IIA and IIB both have type A blood, and their son, also has type A.
II2	type A	I^AI^A or I^Ai	There is insufficient information to definitively determine her genotype. This is because we do not know the genotype of her mother, and her son has the same blood type as she does.
II3	type AB	I^AI^B	This is the only genotype for type AB blood.
II4	type B	I^Bi	She has to be heterozygous for type B blood because all of her children have type O blood; therefore, she would have to have the recessive "*i*" allele.
II5	type A	I^Ai	He has to be heterozygous for type A blood because all of his children have type O blood; therefore, he would have to have the recessive "*i*" allele.

Individual	Phenotype	Genotype(s)	Explanation
II6	type AB	I^AI^B	This is the only genotype for type AB blood.
II7	type A	I^Ai	He would inherit the A allele from his father, and the recessive "*i*" allele from his mother.
II8	type O	*ii*	This is the only possible genotype for type O blood.
III1	type A	I^AI^A or I^Ai	There is insufficient information to definitely determine his genotype. We are not sure of the genotypes of his parents so we would not be able to determine his genotype.
III2	type O	*ii*	This is the only possible genotype for type O blood.
III3	type O	*ii*	This is the only possible genotype for type O blood.
III4	type O	*ii*	This is the only possible genotype for type O blood.
III5	type A	I^Ai	Her mother has type AB blood and her father has type A blood but inherited the recessive allele from his mother, I5. Ana would have inherited the A allele from her mother, and the recessive "*i*" allele from her father.
III6	type B	I^Bi	His mother has type AB blood and his father has type A blood but inherited the recessive allele from his mother, I5. Sean would have inherited the B allele from his mother, and the recessive "*i*" allele from his father.

3. III3 has blood type O. Her genotype is "*ii*." Her husband has type AB blood and would have the genotype I^AI^B. The only phenotypes that their children can have are type A (genotype I^Ai) or type B (genotype I^Bi).
4. Both II1 and II2 have blood type A. If the blood type of the second child helped to determine that both parents have the genotype of I^Ai, then the child has type O blood. This child would have inherited one recessive allele from each parent.
5. The limitations of trying to study human genetics are that in many cases researchers cannot accumulate large numbers of offspring from the same parents in order to improve the statistical reliability of their data. We are limited by the amount of information that a pedigree chart can provide.
6. Blood typing cannot be used to definitely identify the father of a particular child. For example, if the child has type A blood, the mother has type A blood, and the man has type A blood, then you could state the man "might" be the father. However, there are many men that have type A blood so you would not be able to say for sure that he is the father. You can use blood typing to rule out a man as the biological factor. For example, if the man has type AB blood and the child has type O blood, then you know for sure that he is not the father.

Assessment Options

- Collect and assess students' answers to the Analysis questions.

Section 17.3 Review Answers

Student Textbook page 617

1. Corn and canola have been developed through selective breeding techniques.
2. Researchers studying human genetics use pedigrees to study human patterns of inheritance and traits in a family over many generations. Researchers studying *Drosophila* can breed large numbers of flies and many generations

over months, which is not possible with organisms that have longer life cycles.

3. **(a)** The trait is autosomal dominant. It is present in both sexes in each generation.

   (b) Polydactyly, Huntington's disease, and Marfan syndrome are autosomal dominant genetic conditions in humans. There are approximately 2 200 known autosomal dominant conditions, some of the most common being:

   Disorder and frequency / 1000 births

   - dominant otosclerosis 3
   - familial hypercholesterolemia 2
   - dominant congenital deafness 0.1

   (c) Individual I1's genotype is heterozygous.

   (d) II2 is heterozygous and II1 is recessive; therefore, the predicted genotypic ratios for their children would be 0.5 heterozygous and 0.5 recessive. Chance accounts for this difference. The probability is $0.5 \times 0.5 \times 0.5 = 0.125$ or 12.5 percent that they could have three children who all carry the recessive trait.

4. Whether the condition is eliminated or not from the population over time depends on the frequency in the population. One would expect the frequency to be low, but since it is recessive this allele can remain in the population in the heterozygous genotype.

5. Genetic counsellors can estimate the risk of inheriting a particular genetic condition. As well, they can explain the symptoms of genetic conditions and the available treatments, provide other information, and, equally importantly, give emotional support. Students may suggest they would like the genetic counsellor to be intelligent, caring, a good listener, and well educated in the field of genetics.

Connections (Social and Environmental Contexts) Biobanks

Student Textbook page 618

Teaching Strategies

- Have your students research this topic individually and write a position paper on the issue of population biobanks. You can use question 2 and Assessment Checklist 7 Independent Research Skills (in Appendix A) as starting points for student research. There are a number of guides to writing position papers found on the Internet. Select a template from one of these sources that fits the time that you have available and the ability of your students.
- Download and print out a couple of articles on population biobanks for your students. Use Socratic questioning techniques to guide a general class discussion on this topic.

Answers to Questions

1. One country that has already established biobanking is the United Kingdom. Research efforts at the UK Biobank are focussed on improving the prevention, diagnosis, and treatment of illness, and the promotion of health throughout society. Participation in the UK Biobank will be voluntary. All aspects of recruitment, from initial contact with potential participants through to enrolment, will be conducted in a way that preserves the voluntary nature of participation and respects cultural differences. Volunteers will be consenting to "participate in UK Biobank." Given that it will be impossible to anticipate in advance all the ways in which the resource will be used, consent will be based on an explanation and the understanding of, amongst other things, the purpose of UK Biobank; the fact that UK Biobank will be the legal owner of the database and sample collection; the kinds of safeguards that will be maintained; and the policy for making decisions on research access. Participants will have the right to withdraw at any time without having to explain why and without penalty. During enrolment UK Biobank will explain to participants what withdrawal entails. UK Biobank will not enrol potential participants who express the view that they would want to be withdrawn from UK Biobank should they lose mental capacity or die, as this would undermine the value of the resource for research.

   The consent to participate in the project will apply throughout the lifetime of UK Biobank unless the participant withdraws. Further consent will be sought for proposed activities that do not fall within the existing consent.
   Information taken from:
   www.ukbiobank.ac.uk/docs/egf-summary.doc

2. Questions that are likely to need answering to help inform and clarify opinions include:

   What steps are necessary to obtain and maintain the public trust? Which individuals, from which segments of the population, will be sampled? How will the approval of individuals, and Canadian society as a whole, be obtained? Who is in charge? What rights of ownership do sampled individuals give up—and to whom? How will privacy be ensured, and who will be accountable? Should individuals have access to their personal results, or only to those of the aggregate (that is, the population)? What constitutes a benefit in terms of a population, and how is this to be measured? How will all humanity share in and have access to the benefits of biobank research? How will genetic information be used? Who will own the data and information obtained? How will privacy and human rights be protected? How will Canada's patent policies and procedures keep pace with developments in the Canadian biotechnology industry, thereby encouraging greater research and development and commercialization, while also ensuring that the appropriate balance between inventors and citizens is maintained?

If an individual "passes the buck" and does not participate in the debate, then s/he cannot be active in shaping the policies related to biobanking. Their opinions will not be heard, and they will not be able to influence the outcome. They will be leaving the outcome of this important issue to others, who may not share the same opinions.

Web links to further information on biobanking in Canada can be found at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links.

Chapter 17 Review Answers

Student Textbook pages 620–621

Answers to Understanding Concepts Questions

1. Pea plants were an excellent choice of organism because the plants are true-breeding, and self-pollinating, so Mendel could control the breeding. Each of the seven characteristics Mendel tested occurs in two distinct forms, dominant and recessive. There are no intermediates or blending, as would occur if their genes showed incomplete dominance or co-dominance.

2. Mendel's law of segregation states that all individuals have two copies (alleles) of each factor (gene). These copies (alleles) separate randomly during gamete formation, and each gamete receives one copy of every factor (gene).

3. (a) Drooping eyelid genotypes are *DD* and *Dd*.

(b)

	♂ *D*	*d*
♀ *d*	*Dd*	*dd*
d	*Dd*	*dd*

Genotype ratio = 1 Dd:1dd

Phenotype ratio = 1 drooping eyelids:1 non-drooping eyelids

(c) The woman is heterozygous.

4. The probability of one child being albino is still 0.25, regardless of whether previous children are albino. An example of this reasoning would be that the probability of a coin toss is 0.5 "heads" and 0.5 "tails", regardless of whether the coin is tossed ten times and comes up ten "heads". The probability of the eleventh toss is still 0.5 "heads" and 0.5 "tails". All things being equal, the probability of a previous event does not affect the probability of future events.

5. (a) The genotypes of the F_1 generation are all *Pp*. This is the only genotype that would provide three phenotypes in the F_1 generation.

(b) Punnett square of the F_2 is

	P	*p*
P	*PP*	*Pp*
p	*Pp*	*pp*

Genotype ratio = 1 pp:2Pp:1pp

Phenotype ratio = 1 purple:2 lavender:1 white

(c) This cross reveals incomplete dominance
Neiter purple nor white are dominant; they show a blending of their characteristics in the lavender phenotype.

6. A test cross is used to determine if a dominant individual is homozygous or heterozygous when the genotype is unknown. The individual of unknown genotype is crossed with a recessive individual, and if any recessives show in the offspring then the parent is heterozygous. If all offspring show the dominant trait, then it is presumed that the parent is homozygous dominant.

7. Mendel's law of independent assortment requires revision due to the process of crossing over, and the formation of offspring that have different combinations of traits compared to the parents. Linked genes do not assort independently.

8. (a) First grey male mouse—*GG,* albino female—*gg*, second grey male—*Gg*

(b) F_1 male *Gg* x female *Gg* would result in expected phenotypes in F_2 of 3 grey: 1 albino.

9. Blood types among the children could be types A, B, and AB. The man would be heterozygous type B, if any child were blood type A.

10. Possible genotypes of the father are I^AI^B, I^AI^O, and I^BI^O.

11. In females that are heterozygous for an observable sex-linked trait, such as a fur colour in a calico cat, each cell will have one X chromosome that is inactive in the form of a Barr body. The choice of which X chromosome becomes inactive is random. The calico cat has patches of orange and black fur because it has the allele for orange fur colour on one X chromosome, and the allele for black fur colour on the other X chromosome.

12. Only the stallions have the Y sex chromosome. The female offspring have XX sex chromosomes and therefore cannot pass a Y chromosome to their sons.

13. The P generation seeds are round (*R*) yellow (*Y*), and wrinkled (*r*) green (*y*). The F_1 generation seeds are all round and yellow. The F_2 generation seeds are round yellow, round green, wrinkled yellow, and wrinkled green indicating that the alleles for the two characteristics, seed shape and seed colour, segregate independently. That is,

the F_1 generation will produce four different gametes *RY*, *Ry*, *rY*, and *ry* if the chromosomes segregate independently during gamete formation in meiosis. The principle is independent assortment.

Answers to Applying Concepts Questions

14. No, you could not establish true-breeding platinum foxes, as the genotype for the form is heterozygous. A cross between *Pp* and *Pp* (platinum-coloured fur) parents will produce 0.25 *PP* (lethal), 0.5 *Pp* (platinum-coloured fur), and 0.25 *pp* (silver fur colour).

15. (a) Rudy is X^CY and Sinead is X^CX^c; therefore the girl will have the probabilities 0.5 X^CX^c normal colour vision (but a carrier for the colour blindness allele), and 0.5 X^CX^C normal colour vision. The chance of having a colour blind girl is 0.

(b) The probability of a boy with normal vision is 0.5 X^CY.

16. (a) The gene for wing shape is Y-linked. As the X chromosome is inherited from the female parent, some of the males would have normal wings if the gene for wing shape were X-linked.

(b) Cross F_1 females from the previous cross (normal-winged females and the stunted-winged male) with normal-winged males. If the gene is X-linked, then F_1 heterozygous females crossed with a normal-winged male will produce 0.5 of the F_2 males with stunted wings.

17. (a) If Mendel had selected traits that were linked, he would have noticed different phenotypic ratios from those described. Instead of the dihybrid 9:3:3:1 ratio, he would have ratios typical of evidence of recombination due to crossing over, such as 0.42:0.41:0.09:0.8. He would have combinations of traits not present in the parents.

(b) Students' answers will depend on their level of understanding of Mendellian genetics and crossing over. One possible hypothesis that Mendel might have tested is if the traits are carried on the same chromosome, then a cross between two plants—one plant pure breeding for both dominant traits, and the second plant pure breeding for both recessive traits, should produce offspring that only display the dominant phenotype.

(c) Mendel could have crossed the two parental plants, e.g., maternal pure breeding dominant for both traits, and paternal pure breeding recessive for both traits. He may have observed recombinants in the F_1 phenotypes, indicating that there was crossing over of the maternal and paternal genes.

18. Polled is dominant because two heterozygous polled cattle could produce horned cattle. If polled were a recessive trait, then crosses between two recessive individuals would only produce offspring with the recessive phenotype. A dominant phenotype could not be produced because there would be no dominant allele.

19. (a) The farmer could selectively breed tall corn plants and harvest the seeds from the offspring and then repeat the process again and again.

(b) The farmer's work would be easiest if the height of corn plants were determined by multiple alleles or co-dominance because then he/she could select only the tall plants to breed, instead of working with varying heights produced by polygenic inheritance.

(c) The farmer would test various parent crosses e.g. tall plants with tall plants, medium height with medium height, and short with short to see if the offspring of particular crosses of heights show evidence of the disease.

(d) The farmer would avoid selecting any plant for breeding that showed the disease and then select only the tall plants for breeding from the disease-free offspring.

20. If the genes are linked but very close together, then crossing over is unlikely to produce different combinations in the gametes. Alternatively, if the genes are so far apart from each other that crossovers occur often, then the frequency of recombination between these genes could have a maximum value of 50 percent, which would be indistinguishable from genes on different chromosomes.

21. OI displays autosomal recessive inheritance. I1, II1-II5: are heterozygous; I2, III2, and III3 are homozygous recessive; III1 and III4 are heterozygous or homozygous dominant, it is uncertain which. I2, III2, and III3 have OI. All other individuals have normal phenotypes.

Answers to Making Connections Questions

22. (a) What is the probability that we could have a child with cystic fibrosis (CF)? If we were to have a child, would the treatment be any different from Brian's sister? Are there different degrees of severity within relatives that have CF? Is there the likelihood of a cure for CF being developed?

(b) Brian's sister has inherited the disease from her parents. The parents are carriers for the disease but do not have the symptoms of the disease. In other words, they are heterozygous for CF. The probability that Brian is also heterozygous for CF is 0.5. There are many genetic variations of the CF gene, and, as a result, there are varying degrees of severity. At present the symptoms are treatable; however, there is no cure.

(c) Does Sarah have any history of CF in her family? If not, then it is unlikely that she is a carrier like Brian's parents. Assuming this to be the case, then there is a 0.5 probability that their children would also be carriers, but none would have the disease.

23. The most successful presentations will stay on topic and provide arguments that clearly address the question provided. Accept any reasonable and well-presented points of view that address both sides of the issue.

24. This information can help children understand that being carriers of a genetic disorder means that the disorder could be present in their children, if their spouse has the same gene. For minor disorders, such as colour blindness, this may seem trivial, but helping children understand how traits are inherited provides them with the knowledge to make informed decisions.

25. Inbreeding (breeding animals that are closely related, such as siblings or cousins), results in a greater probability that undesirable traits will be exhibited as these individuals often carry the same recessive alleles. There is less chance of the genetic disorder appearing if very distantly related breeding stock is selected from other breeders.

CHAPTER 18 MOLECULAR GENETICS

Curriculum Correlation

General Outcome 3: Students will explain classical genetics at the molecular level.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
30–C3.1k summarize the historical events that led to the discovery of the structure of the DNA molecule, as described by Watson and Crick	Section 18.1: Isolating the Material of Heredity, p. 624 The Transforming Principle, p. 624 Hershey and Chase: Evidence in Favour of DNA as the Hereditary Material, p. 624 The Structure of DNA, p. 626 The Chemical Composition of DNA, p. 626 The Three-Dimensional Structure of DNA, p. 627 The Double Helix Structure of DNA, p. 628	Questions for Comprehension: 1–3, p. 625 4, p. 629 Section 18.1 Review: 1, 2, 5, p. 635 Chapter 18 Review: 1, 2, p. 664 Chapter 18 Test Unit 7 Review: 42, p. 671
30–C3.2k describe, in general, how genetic information is contained in the sequence of bases in DNA molecules in chromosomes; how the DNA molecules replicate themselves; and how the genetic information is transcribed into sequences of bases in RNA molecules and is finally translated into sequences of amino acids in proteins	Section 18.1: RNA, p. 629 Genes and the Genome, p. 629 DNA Replication, p. 630 Semi-Conservative Replication, p. 630 Initiation, p. 630 Elongation and Transmission, p. 631 Throughout Section 18.2, pp. 636–642 Thought Lab 18.1: DNA Deductions, p. 629 Investigation 18.A: Modelling DNA Structure and Replication, p. 634 Thought Lab 18.2: Transcription in Reverse, p. 639 Investigation 18.B: Simulating Protein Synthesis, p. 641	Questions for Comprehension: 6, p. 630 7–10, p. 632 13, 14, p. 637 15, 16, p. 640 Practice Problems: 3–5, p. 637 6, 7, p. 638 Thought Lab 18.1: Analysis, p. 629 Investigation 18.A: Analysis, p. 634 Thought Lab 18.2: Analysis, p. 639 Investigation 18.B: Analysis, Conclusion, p. 641 Section 18.1 Review: 6–9, p. 635 Section 18.2 Review: 1–10, p. 642 Chapter 18 Review: 3–10, 16, 17, 21, 23, pp. 664–665 Chapter 18 Test Unit 7 Review: 15–18, 43, 48, pp. 669–67
30–C3.3k explain, in general, how restriction enzymes cut DNA molecules into smaller fragments and how ligases reassemble them	Section 18.3: Restriction Endonucleases and DNA Ligases, p. 648 Investigation 18.A: Modelling DNA Structure and Replication, p. 634	Questions for Comprehension: 23, p. 649 Investigation 18.A: Analysis, p. 634 Section 18.3 Review: 5, p. 651 Chapter 18 Review: 12–13, p. 664 Chapter 18 Test Unit 7 Review: 19, 22, 27, p. 669

	Student Textbook	Assessment Options
30–C3.4k explain, in general, how cells may be transformed by inserting new DNA sequences into their genomes	Section 18.3: Recombinant DNA, p. 647 Sorting and Analyzing DNA, p. 649 Thought Lab 18.4: Recreating the First Chimera, p. 649 Section 18.4 Gathering and Managing Genetic Information, p. 652	Questions for Comprehension: 23, p. 649 Thought Lab 18.4: Analysis, p. 649 Section 18.3 Review: 6, 7, p. 651 Chapter 18 Review: 12, 13, 19, 20, pp. 664–665 Chapter 18 Test Unit 7 Review: 19, 22, 39, 43–47, pp. 669–671
30–C3.5k explain how a random change (mutation) in the sequence of bases provides a source of genetic variability	Section 18.3: Types of Mutations, p. 643 Causes of Mutations, p. 644 Physical Mutagens, p. 645 Chemical Mutagens, p. 645 Mutations and Genetic Variation, p. 645	Questions for Comprehension: 17–19, p. 644 20, p. 645 Section 18.3 Review: 1–4, 6, p. 651 Chapter 18 Review: 11, 26, pp. 664–665 Chapter 18 Test Unit 7 Review: 9 (a), 21, 37, 38, pp. 668–670
30–C3.6k explain how information in nucleic acids contained in the nucleus, mitochondria and chloroplasts gives evidence for the relationships among organisms of different species	Section 18.3: Tracing Ancestry Through Mitochondrial DNA, p. 646 Genetic Variation Within Species, p. 647 Thought Lab 18.3: Investigating Cancer Genes, p. 646	Questions for Comprehension: 21, 22, p. 647 Thought Lab 18.3: Analysis, p. 646 Chapter 18 Review: 22, p. 665 Chapter 18 Test Unit 7 Review: 47, p. 671
Outcomes for Science, Technology, and Society (Emphasis on social and environmental contexts)		
30–C3.1sts explain that science and technology have both intended and unintended consequences for humans and the environment by ■ *discussing the implications for society of corporations being able to patent genes, e.g., gene for Roundup resistance in canola*	Section 18.4: Gathering and Managing Genetic Information, p. 652 Public Benefits of Genetic Research, p. 653 Ownership of Genetic Information, p. 653 Patenting Organisms and Genes, p. 653 Assessing the Risks, p. 657 e.g., Connections: Social and Environmental Contexts: Biotechnology: Assessing Unintended Consequences, p. 662	Connections: Social and Environmental Contexts, p. 662 Section 18.4 Review: 3, 4, p. 661 Chapter 18 Review: 24, 26, 28, p. 665 Unit 7 Review: 44–46, 48, p. 671
■ *assessing the concerns and benefits of genetically modified organisms, e.g., transgenic food organisms, tree cloning for reforestation*	Section 18.4: Public Benefits of Genetic Research, p. 653 Ownership of Genetic Information, p. 653 Biotechnology Products, p. 654 Medicinal Bacteria, p. 654 Transgenic Plants, p. 655 Cloned and Transgenic Animals, p. 655 Assessing the Risks, p. 657 Connections: Social and Environmental Contexts: Biotechnology: Assessing Unintended Consequences, p. 662	Questions for Comprehension: 27, 28, p. 658 Connections: Social and Environmental Contexts, 1, 2, p. 662 Section 18.4 Review: 3, 4, p. 661 Chapter 18 Review: 24, 27, p. 665 Unit 7 Review: 39, 45, 46, 48, pp. 670–671

	Student Textbook	Assessment Options
30–C3.2sts explain that scientific research and technological development help achieve a sustainable society, economy and environment by ■ *discussing the Human Genome Project and the potential of proteomic technologies, in terms of the needs, interests and financial support of society*	Section 18.2: Genomics and Proteomics, p. 640 Section 18.4: Assessing the Risks, p. 657 Connections: Social and Environmental Contexts: Biotechnology: Assessing Unintended Consequences, p. 662 Career Focus: Ask a Cancer Geneticist, p. 666	Questions for Comprehension: 27, 28, p. 658 Connections: Social and Environmental Contexts, 1, 2, p. 662 Section 18.4 Review: 1, p. 661 Chapter 18 Review: 21, 24, p. 665 Unit 7 Review: 43, e.g., 46, p. 671
■ *discussing biotechnology and gene replacement therapy in the treatment of human genetic disorders*	Section 18.4: Medicinal Bacteria, p. 654 The Diagnosis and Treatment of Genetic Disorders, p. 658 Prenatal Diagnosis and Screening, p. 658 Treating Human Genetic Disorders, p. 660	Questions for Comprehension: 27, 28, p. 658 Chapter 18 Review: 28, p. 665 Unit 7 Review: 35, e.g., 44, pp. 670–671
■ *assessing the impact and value of DNA sequencing on the study of genetic relationships and variations in population ecology*	Section 18.4: The Diagnosis and Treatment of Genetic Disorders, p. 658 Treating Human Genetic Diseases, p. 660	Questions for Comprehension: 29, p. 660 Section 18.4 Review: 1, p. 661 Unit 7 Review: 48, p. 671
■ *exploring the application of nanotechnology and its implications for clinical diagnostics, pharmacology, biological research or proteomic programs.*	Section 18.4: Gathering and Managing Genetic Information, p. 652 The Diagnosis and Treatment of Genetic Disorders, p. 658 Prenatal Diagnosis and Screening, p. 658 Treating Human Genetic Disorders, p. 660 Career Focus: Ask a Cancer Geneticist, p. 666	Questions for Comprehension: 24–26, p. 653 29, p. 660 Section 18.4 Review: 2, 5–7, p. 661 Chapter 18 Review: 15, 25, 28, pp. 664–665 Unit 7 Review: 19, 42, 44, 46, 48, pp. 669–671
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
30–C3.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues, e.g., by ■ *designing an experiment to identify the proteins produced in a cell at a particular point in time or development, e.g., microarrays*	Investigation 18.A: Modelling DNA Structure and Replication, p. 634 Thought Lab 18.4: Recreating the First Chimera, p. 649 Section 18.4: Gathering and Managing Genetic Information, p. 652 Public Benefits of Genetic Research, p. 653	Investigation 18.A, Analysis, p. 634 Thought Lab 18.4, Analysis, p. 649 Chapter 18 Review: 20, p. 665
Performing and Recording		
30–C3.2s conduct investigations into relationships between and among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ constructing models of DNA to demonstrate the general structure and base arrangement	Launch Lab: DNA Extraction, p. 623 Thought Lab 18.1: DNA Deductions, p. 629 Investigation 18.A: Modelling DNA Structure and Replication, p. 634 Thought Lab 18.2: Transcription in Reverse, p. 639	Launch Lab: Analysis, p. 623 Thought Lab 18.1: Analysis, p. 629 Investigation 18.A: Analysis, p. 634 Thought Lab 18.2: Analysis, p. 639
■ performing simulations to demonstrate the replication of DNA and the transcription and translation of its information	Thought Lab 18.2: Transcription in Reverse, p. 639 Investigation 18.B: Simulating Protein Synthesis, p. 641	Thought Lab 18.2: Analysis, p. 639 Investigation 18.B: Analysis, Conclusion, p. 641

	Student Textbook	Assessment Options
■ performing simulations to demonstrate the use of restriction enzymes and ligases	Thought Lab 18.4: Recreating the First Chimera, p. 649	Thought Lab 18.4: Analysis, p. 649
■ *performing an investigation to extract DNA from cells, e.g., green peas or beans, bananas or onions*	Launch Lab: DNA Extraction, p. 623	Launch Lab: Analysis, p. 623
■ *researching gel electrophoresis techniques and their applications in medical diagnostics and forensics*	Section 18.3: Recombinant DNA, p. 647 Sorting and Analyzing DNA, p. 649	Chapter 18 Review: 19, p. 665 Unit 7 Review: 23, p. 669
Analyzing and Interpreting		
30–C3.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ analyzing relationships, from published data, between human activities and changes in genetic information that lead to heritable mutations and cancer	Thought Lab 18.1: DNA Deductions, p. 629 Thought Lab 18.3: Investigating Cancer Genes, p. 646	Thought Lab 18.1: Analysis, p. 629 Thought Lab 18.3: Analysis, p. 646 Section 18.3 Review: 3, p. 651 Unit 7 Review: 38, p. 670
■ *analyzing DNA fingerprints*	Thought Lab 18.5: Reading a DNA Fingerprint, p. 651	Thought Lab 18.5: Analysis, p. 651 Chapter 18 Review: 23, p, 665 Unit 7 Review: 36, p. 670
Communication and Teamwork		
30–C3.4s work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ *working cooperatively with team members to investigate the impact of an environmental factor on the expression of a gene and solving problems as they arise*	Investigation 18.A: Modelling DNA Structure and Replication, p. 634 Investigation 18.B: Simulating Protein Synthesis, p. 641 Thought Lab 18.3: Investigating Cancer Genes, p. 646	Investigation 18.A: Analysis, p. 634 Investigation 18.B: Analysis, Conclusion p. 641 Thought Lab 18.3: Analysis, p. 646

Chapter 18

Molecular Genetics

Student Textbook page 622–665

Chapter Concepts

18.1 DNA Structure and Replication

- A molecule of DNA is made up of two long strands of nucleotides wound around each other in the shape of a double helix.
- During DNA replication, complementary base pairing ensures that each daughter molecule is identical to the original DNA molecule.

18.2 Protein Synthesis and Gene Expression

- Gene expression involves two basic steps: transcription of genetic information from DNA to RNA, then translation from RNA to protein.
- The genetic code is made up of nucleotide triplets called codons. Each codon corresponds to a specific amino acid.

18.3 Mutations and Genetic Recombination

- Permanent changes in DNA give rise to genetic variation and may also cause hereditary disorders or cancer.

18.4 Genetics and Society

- Genetic technologies have many useful applications but can also give rise to challenging social and ethical questions.

Common Misconceptions

- It is tempting to believe that knowing the location of a gene on a chromosome, or knowing the DNA sequence of a gene that is responsible for a genetic disease, makes it possible to treat or cure the disease. This is very far from reality, however. Identifying a gene responsible for a disease is merely the earliest stage of potentially knowing how to treat it.
- Some students think that "genetic recombination" means using scissors and a scalpel to remove a gene from one piece of DNA, and sutures to attach it to another. All of these processes are carried out chemically in a solution of many strands of DNA.
- Some students may think that only genetically modified foods have DNA. Most living organisms have DNA which is composed of the four nucleotides, adenine (A), thymine (T), cytosine (C), and guanine (G).
- Despite the popular conception that DNA profiling is similar to fingerprint technology, the term "DNA fingerprinting" is a misnomer: While real fingerprints can distinguish between identical twins, DNA analysis cannot. Comparing it to fingerprinting raises misguided expectations.
- Some students may erroneously assume that the bands of DNA that are visible in gel electrophosphoris are single strands of DNA. Remind students that the bands consist of large numbers of stained DNA molecules.
- Despite how it is depicted in popular television shows, extracting DNA and running the gel electrophoresis tests to make the DNA profile cannot yet be done in 30 minutes.

Helpful Resources

Books and Articles

- Watson, James. *The Double Helix*. New York: Touchstone, 1968. ISBN 074321630X
- Maddox, Brenda. *Rosalind Franklin-The Dark Lady of DNA*. United Kingdom: Harper Collins, 2002. ISBN 0060985089
- The movie, *The Double-Helix*, co-produced by the Arts & Entertainment Network and the British Broadcasting Company in 1987, is a very entertaining and educational dramatization of the work of Watson and Crick.
- The Knowledge Network's *100 Greatest Discoveries* DVD series provides an overview of major discoveries in genetics. "From the theory of relativity to the genetic secrets of the human body, Bill Nye takes a stunning look at the scientific discoveries that have changed the world. Find out how the 100 greatest discoveries were made, and how they impact our lives today. The series spotlights scientists that made some of the earliest findings, as well as leading modern day innovators. Through lively and dramatic accounts, the program examines landmark breakthroughs in astronomy, biology, chemistry, earth science, evolution, genetics, medicine and physics."

Web Sites

Web links related to molecular genetics can be found at **www.albertabiology.ca.** Go to the Online Learning Centre, and log on to the Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities; or to supply answers (ANS) for assessment or handouts. The BLMs are in digital form, stored on the CD that accompanies this Teacher's Resource or on the web site at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, BLMs.

Number (Type)

BLM 18.0.1 (HAND) Launch Lab: DNA Extraction
BLM 18.0.1A (ANS) Launch Lab: DNA Extraction Answer Key

BLM 18.1.1 (OH) Griffith's Discovery of Transformation
BLM 18.1.2 (OH) Hershey-Chase Experiment
BLM 18.1.3 (HAND) Genetic Timeline Research Project

BLM 18.1.4 (OH) DNA Nucleotide and Sugar-Phosphate Backbone
BLM 18.1.5 (OH) The Double Helix
BLM 18.1.6 (HAND) Thought Lab 18.1: DNA Deductions
BLM 18.1.6A (ANS) Thought Lab 18.1: DNA Deductions Answer Key
BLM 18.1.7 (OH) DNA Replication
BLM 18.1.8 (HAND) DNA Replication Worksheet
BLM 18.1.8A (ANS) DNA Replication Worksheet Answer Key
BLM 18.1.9 (HAND) Investigation 18.A: Modelling DNA Structure and Replication
BLM 18.1.9A (ANS) Investigation 18.A: Modelling DNA Structure and Replication Answer Key
BLM 18.1.10 (HAND) The DNA Story Worksheet
BLM 18.1.10A (ANS) The DNA Story Worksheet Answer Key

BLM 18.2.1 (OH) The Central Dogma
BLM 18.2.2 (OH) mRNA
BLM 18.2.3 (OH) Table: Messenger RNA Codons and Their Corresponding Amino Acids
BLM 18.2.4 (OH) Transcription
BLM 18.2.5 (OH) tRNA
BLM 18.2.6 (HAND) Thought Lab 18.2: Transcription in Reverse
BLM 18.2.6A (ANS) Thought Lab 18.2: Transcription in Reverse Answer Key
BLM 18.2.7 (OH) Protein Structure
BLM 18.2.8 (OH) The Translation Cycle
BLM 18.2.9 (HAND) Transcription and Translation Worksheet
BLM 18.2.9A (ANS) Transcription and Translation Worksheet Answer Key
BLM 18.2.10 (HAND) Investigation 18.B: Simulating Protein Synthesis
BLM 18.2.10A (ANS) Investigation 18.B: Simulating Protein Synthesis Answer Key
BLM 18.2.11 (OH) Gene Expression

BLM 18.3.1 (OH) Mutations
BLM 18.3.2 (HAND) Mutations Worksheet
BLM 18.3.2A (ANS) Mutations Worksheet Answer Key
BLM 18.3.3 (HAND) Thought Lab 18.3: Investigating Cancer Genes
BLM 18.3.3A (ANS) Thought Lab 18.3: Investigating Cancer Genes Answer Key
BLM 18.3.4 (HAND) Prevention of Cancer
BLM 18.3.5 (HAND) FAQ – Tobacco and Health
BLM 18.3.6 (HAND) Restriction Endonucleases
BLM 18.3.6A (ANS/OH) Restriction Endonucleases Answer Key
BLM 18.3.7 (HAND) Thought Lab 18.4: Recreating the First Chimera
BLM 18.3.7A (ANS) Thought Lab 18.4: Recreating the First Chimera Answer Key
BLM 18.3.8 (HAND) Cohen-Boyer Experiment
BLM 18.3.9 (OH) Gel Electrophoresis
BLM 18.3.10 (HAND) Thought Lab 18.5: Reading a DNA Fingerprint
BLM 18.3.10A (ANS) Thought Lab 18.5: Reading a DNA Fingerprint Answer Key
BLM 18.3.11 (HAND) DNA Fingerprinting

BLM 18.4.1 (OH) DNA Microarray
BLM 18.4.2 (OH) Golden Rice
BLM 18.4.3 (OH) Cloning
BLM 18.4.4 (HAND) Cloning a Carrot
BLM 18.4.5 (OH) Prenatal Diagnosis
BLM 18.4.6 (OH) Gene Therapy

BLM 18.5.1 (HAND) Chapter 18 Test
BLM 18.5.1A (ANS) Chapter 18 Test Answer Key

Using the Chapter 18 Opener

Student Textbook pages 622-623

Teaching Strategies

- Show one of the DVDs listed in the Helpful Resources section above to introduce DNA to your students. The dramatic accounts of the discovery of DNA and genetic engineering will provide a fascinating introduction to this chapter.
- After they have read the chapter opener, involve students in a class discussion on possible moral and ethical questions that the study of molecular genetic may give rise to. Challenge students to bring in news articles or clips concerning these issues and use them to create a display board of current ethical issues.
- Use the Launch Lab: DNA Extraction.

Launch Lab: DNA Extraction

Student Textbook page 623

Purpose

The purpose of this lab is to extract DNA from living tissue.

Outcomes

- 30–C3.2s

Advance Preparation

When to Begin	What to Do
4 to 5 days before	■ Purchase the necessary materials to complete the lab
1 or 2 days before	■ Photocopy **BLM 18.0.1 (HAND) Launch Lab: DNA Extraction.**

Materials

- mortar and pestle
- graduated cylinder
- 250 mL beaker
- small piece of animal tissue
- 50 mL beakers (2)
- glass stirring rod
- cheesecloth
- 0.9 % NaCl solution
- 10 % detergent solution
- 95 % ice-cold ethanol solution
- meat tenderizer (optional)

Time Required

30 to 45 minutes

Helpful Tips

- Use **BLM 18.0.1 (HAND) Launch Lab: DNA Extraction** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 18.0.1A (ANS) Launch Lab: DNA Extraction Answer Key**.
- Stress that students are working with biotechnology and that certain protocols must be followed. For example, making sure that all of the glassware that they are using in this investigation is very clean.
- To make a 0.9% NaCl solution, dissolve 0.9 grams of sodium chloride in 91.1 grams of distilled water.
- To make a 10% detergent solution, add 10 grams of detergent to 90 grams of water.
- Lab-grade ethanol is a 95% solution.
- Use a detergent (e.g. Woolite™) that contains SDS (sodium dodecyl sulfate). SDS detergent causes the cell membrane to break down by emulsifying the lipids and proteins of the cell, and disrupting the polar interactions that hold the cell membrane together. The detergent then forms complexes with these lipids and proteins, causing them to precipitate out of solution.
- The use of NaCl shields the negative phosphate ends of the DNA. This allows the ends to come closer, so they can precipitate out of a cold 95% ethyl alcohol solution.
- A blender is much easier to use—especially if you are going to grind up animal tissue such as liver. You should place the liver into the food blender and cover the liver with sufficient salt water to completely immerse the tissue. Blend the mixture until it acquires the consistency of watery oatmeal.
- Adding a pinch of meat tenderizer will also help break down the animal tissue.
- You can use this basic procedure to extract DNA from bananas or onions. Have half of your students extract the DNA from animal tissue while the other half is extracting the DNA from plant tissue. Ask them to predict the difference between the DNA in both samples. Note: both samples will be identical.
- Show students the X-ray crystallography image of DNA that was taken by Rosalind Franklin in the 1950s as part of your closing discussion. This will help the students answer Analysis question 2.
- *Expected Results:* Students might be expecting to see the double-helix, with the base-pairings nicely coloured. However, the DNA that they collect will be a white, thread-like structure that could be folded into a "fuzzy white ball" in the bottom of their test tube.

  Students will be altering the filtrate so that the DNA can be spooled out when it precipitates. The DNA is soluble in the detergent solution but is insoluble in the alcohol. When students add the chilled alcohol, the DNA will come out of solution and easily spool on a glass rod.

Safety Precautions

- Stress the importance of wearing safety equipment throughout this investigation.
- If you are using animal tissue, make sure that you follow the safety protocols outlined in the *Safety in the Classroom* document developed by Alberta Education. This document is available on the Alberta Education web site or at the Online Learning Centre, Instructor Edition, Teacher Web Links.

Answers to Analysis Questions

1. The DNA will look like a thin piece of white thread as it is spooled on the glass stirring rod.
2. Students' answers will depend on their observations and description of the DNA that they extract during this investigation. Students might suggest that researchers could take the thin strand of DNA and conduct tests that would give them more information on the chemistry of this molecule or the researchers might be able to take x-rays of the molecule. Students' answers might make the link between DNA studies and the forensic use of DNA that has been popularized in many of today's television shows and movies.

Assessment Options

- Collect and assess answers to the Analysis questions.

18.1 DNA Structure and Replication

Student Textbook pages 624–635

Section Outcomes

Students will:

- summarize the events and experiments that led to the discovery of the structure of DNA

- explain how the interaction between DNA and proteins results in the accurate replication of genetic information
- design and construct models to simulate the structure and replication of DNA

Key Terms

deoxyribonucleic acid (DNA)
ribonucleic acid (RNA)
transforming principle
nucleotides
Chargaff's rule
complementary base pairs
antiparallel
gene
genome
replication
semi-conservative
replication origin
helicases
replication bubble
replication fork
DNA polymerase
elongation
primer
leading strand
lagging strand
Okazaki fragments
DNA ligase
primase
replication machine
termination
DNA sequencing
Human Genome Project

Biology Background

- To analyze the structure of DNA, Rosalind Franklin used a specific technique called X-ray crystallography, in which x-rays are passed through a perfect crystal to produce a diffraction pattern. Through this process, scientists like Franklin in the 1950s were able to determine the location of atoms in molecules as complex as DNA. At first these images were unclear, as two different forms of DNA, A and B DNA, were being x-rayed together. Franklin developed a unique method of separating these two forms of DNA, allowing her to generate clear images of the B form of DNA. A combination of the information gained from these images and a dose of good old-fashioned scientific reasoning led her to discover essential components of the DNA structure—the position of the sugar-phosphate backbone on the outside of the DNA molecule, the shape and repeating pattern of its double helix structure, and the double stranded nature of the hereditary molecule (it was initially believed to be triple stranded).
- Genomics is a branch of biology that involves the study of entire genomes. The science was born in 1972, when Walter Fiers, a Belgian scientist, and his colleagues, sequenced the first gene (for the coat protein of RNA bacteriophage MS2) and entire genome (of the same bacteriophage). The first DNA genome (DNA virus ϕX174) was later sequenced in 1977 by double Nobel laureate, British-born biochemist Frank Sanger. To date, the genomes of approximately 1000 viruses, 220 bacteria, and 20 eukaryotes have been sequenced. Included in the latter category are the yeast *Saccharomyces cerevisiae*, the flower *Arabidopsis thaliana*, the worm *Caenorhabditis elegans*, the fruit fly *Drosophila melanogaster*, and the zebrafish *Brachydanio rerio*.
- "Junk" DNA, DNA for which there is no known function, is found in the genomes of most organisms. The human genome contains approximately 90% junk DNA; however, some species, such as the Japanese pufferfish (*Takifugi rubripes*) and the spotted green pufferfish (*Tetraodon nigroviridis*) have very little junk DNA. While some junk DNA appears to be non-coding, some nucleotide sequences labelled as junk have later been shown to encode specific genes. There are numerous hypotheses regarding the origin of junk DNA. These include the following: junk DNA sequences were once coding genes, but have lost their functionality over years of evolution; junk DNA acts as a "gene reservoir" from which possible new functional genes may arise as a consequence of mutations; junk DNA entered the genome as transposons, or "jumping genes;" junk DNA simply codes for genes that have not yet been discovered; junk DNA acts as a spacer that enables enzyme complexes to bind with functional genes more easily.
- While the Human Genome Project has claimed to sequence a "normal" human genome, there is some discrepancy as to what "normal" really is. Recently, scientists have discovered that a greater number of DNA differences exist between human beings exhibiting a normal phenotype than was originally thought. Indeed, some karyotypes that were thought to produce developmental delays and other genetic abnormalities have been found in individuals with completely normal phenotypes. These findings may have significant implications for genetic screening and extrapolation of human genome data to individuals.
- While the human genome project was "completed" in April 2003, many unknown aspects of the human genome still remain. Coding of repetitive sequences of DNA, such as that found at the telomeres (DNA found at the ends of chromosomes) and centromeres, were not fully sequenced due to limitations in technology that have not yet been overcome. Other large gaps throughout the genome also remain unfinished, but are being completed with time.

Teaching Strategies

- You could start this section by reading some excerpts from James Watson's *The Double Helix* or showing an introductory level video, such as the Knowledge Network's *100 Greatest Discoveries* DVD, that traces the events and

experiments that lead to the discovery of the structure of DNA.

- **BLM 18.1.1 (OH) Griffith's Discovery of Transformation** and **BLM 18.1.2 (OH) Hershey-Chase Experiment** can be used as overhead teaching aids when reviewing these experiments with your students. The diagrams provided in the BLMs are similar to those shown in the textbook and provide space for students to record information associated with each diagram.
- **BLM 18.1.3 (HAND) Genetic Timeline Research Project** challenges students to further describe the role played by various scientists in the investigation of the structure and function of DNA.
- Use **BLM 18.1.4 (OH) DNA Nucleotides and Sugar-Phosphate Backbone, BLM 18.1.5 (OH) The Double Helix,** and **BLM 18.1.7 (OH) DNA Replication** to provide visual support when teaching DNA structure and replication. Most students will have difficulty visualizing the structure of DNA in three dimensions. Consider using a model to enhance students' perception of the DNA molecule.
- **BLM 18.1.8 (HAND) DNA Replication Worksheet** and **BLM 18.1.10 (HAND) The DNA Story Worksheet** reinforce students' knowledge of the main chapter concepts. Assign as a take-home worksheet or in class quiz.
- Arrange to have a computer, Internet access, and an LCD projector in your room. There are many web sites that have videos and/or animations that deal with the structure of DNA and the replication of this unique molecule.

Answers to Questions for Comprehension

Student Textbook page 625

Q1. Miescher's contribution to the study of hereditary materials was the isolation of a weakly acidic phosphorous-containing substance from the nuclei of white blood cells, which he termed "nucleic acid."

Q2. Avery, MacLeod, and McCarty conducted a series of experiments and discovered the following:

- When they heat-killed pathogenic bacteria with a protein-destroying enzyme, transformation still occurred.
- When they treated heat-killed pathogenic bacteria with a DNA-destroying enzyme, transformation did not occur.

These results provided strong evidence for DNA's role in transformation.

Q3. Hershey and Chase concluded that genes are made of DNA.

Answers to Practice Problems

Student Textbook page 627

1. Problem

A sample of DNA contains A and C nucleotides in the following proportions: A = 34% and C = 16%. What are the proportions of G and T nucleotides in this sample? (Assume that the characteristic proportions are exactly equal.)

What Is Required?

You must determine the proportion of G and T nucleotides in the sample.

What Is Given?

The proportion of A nucleotides in the sample is 34%.

The proportion of C nucleotides in the sample is 16%.

Plan Your Strategy

Use Chargaff's rule to determine the proportion of T nucleotides in the sample.

Use Chargaff's rule to determine the proportion of G nucleotides in the sample.

Act on Your Strategy

Step 1 From Chargaff's rule, you know that in any sample of DNA, the amount of adenine (A) is always equal to the amount of thymine (T). Therefore, the proportion of thymine (T) nucleotides in the sample must be 34%.

Step 2 From Chargaff's rule, you know that in any sample of DNA, the amount of cytosine(C) is always equal to the amount of guanine (G). Therefore, the proportion of guanine (G) nucleotides in the sample must be 16%.

Check Your Solution

34% + 16% + 34% + 16% = 100%

2. Problem

Use Chargaff's rule to complete the following table. (Assume that the characteristic proportions are exactly equal.)

Nucleotide Composition of DNA in Sample X

Nucleotide	Proportion (%)
A	24
C	
G	
T	

What Is Required?

You must determine the proportion of C, G, and T nucleotides in the sample.

What Is Given?

The proportion of A nucleotides in the sample is 24%.

Plan Your Strategy

Use Chargaff's rule to determine the proportion of T nucleotides in the sample.

Next, determine the percentage of G and C nucleotides in the sample.

Act on Your Strategy

Step 1 From Chargaff's rule, you know that in any sample of DNA, the amount of adenine (A) is always equal to the amount of thymine (T). Therefore, the proportion of thymine (T) nucleotides in the sample must be 24%.

Step 2 Since the proportion of adenine (A) is 24% and the proportion of thymine (T) is 24%, the total proportion of A and T nucleotides is 24% + 24% = 48%. Because the proportion of nucleotides must add up to 100%, you know the total proportion of guanine (G) and cytosine (C) in the sample must be 100% - 48% = 52%.

From Chargaff's rule, you also know that in any sample of DNA, the amount of cytosine(C) is always equal to the amount of guanine (G). Therefore, the amount of C and G nucleotides in the sample must be 52% ÷ 2 = 26% for each nucleotide.

Check Your Solution

24% + 26% + 24% + 26% = 100%

Answers to Questions for Comprehension

Student Textbook page 629

Q4. (a) Chargaff found that the amount of adenine in any sample of DNA is approximately equal to the amount of thymine, and the amount of cytosine is always approximately equal to the amount of guanine.

(b) Franklin used X-ray photography to analyze the structure of DNA. Her observations provided evidence that DNA has a helical structure with two regularly repeating patterns. She also concluded that the nitrogenous bases were located on the inside of the helical structure, and the sugar-phosphate backbone was located on the outside, facing toward the watery nucleus of the cell.

(c) Watson and Crick were the first to produce a structural model of DNA that could account for all of the experimental evidence gathered to that point in time.

Q5. The nitrogenous bases are different sizes. Adenine and guanine have a double-ring structure while thymine and cytosine have as single-ring structure. The A-T and C-G pairs are called "complementary base pairs" and maintain a constant width of 3 three rings in the DNA molecule.

Thought Lab 18.1: DNA Deductions

Student Textbook page 629

Purpose

The purpose of this activity is for students to analyze data and apply a conceptual model to infer the structure of a DNA molecule.

Outcomes

30-C3.2s

Advance Preparation

When to Begin	What to Do
1 or 2 days before	■ Photocopy **BLM 18.1.6 (HAND) Thought Lab 18.1: DNA Deductions.** ■ Photocopy **BLM 18.1.4 (OH) DNA Nucleotides and Sugan-Phosphate Backbone** ■ Photocopy **BLM 18.1.5 (OH) The Double Helix**, if using.

Time Required

30 minutes

Helpful Tips

- Use **BLM 18.1.6 (HAND) Thought Lab 18.1: DNA Deductions** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 18.1.6A (ANS) Thought Lab 18.1: DNA Deductions Answer Key.**
- Consider distributing photocopies of **BLM 18.1.4 (OH) DNA Nucleotides and Sugar-Phosphate Backbone** and **BLM 18.1.5 (OH) The Double Helix** as guides to help students complete this activity.
- Review Chargaff's rule on page 627 of the textbook. Chargaff found that the amount of adenine in any sample of DNA is approximately equal to the amount of thymine, and the amount of cytosine is always approximately equal to the amount of guanine.
- This activity is very similar to Practice Problems 1 and 2 on page 627 of the student textbook.
- Consider doing this activity as a class discussion. This will save time, and can be used as a formative evaluation tool to see if students understand the basic principles associated with the structure of DNA.

Answers to Procedure Questions

1.

Nucleotide	Presence in DNA sample (percent)
adenine	31
cytosine	19
guanine	19
thymine	31

2. Student diagrams should indicate that adenine-thymine base pairs make up 62 percent of the DNA in this sample, while the cytosine-guanine base pairs would make up the remaining 38 percent of the DNA. If the sample is 20 base pairs long, then 12.4 (round to 12) of them would be A-T and 7.6 (round to 8) would be C-G base pairs. Diagrams should use solid lines to show chemical bonds and dotted lines to show hydrogen bonds.

Answers to Analysis Questions

1. The second DNA sample from the same mouse would be identical. All somatic cells in that mouse contain the same genetic code.

2. The relative percentage composition of the DNA nucleotides would not change even though there is only one chromosome from each pair in the gamete. The total amount of DNA is different, but the percentage composition of the nucleotides would not change.

3. The nucleotide composition of the mouse would be different than the nucleotide composition of the deer because the composition of DNA is unique to each species. However, the percentage of adenine will remain approximately the same as the percentage of thymine, and the percentage of cytosine will remain approximately equal to the percentage of guanine in each species.

Assessment Options

- Collect and assess students' answers to the Procedure and Analysis questions.
- Consider doing this activity as a class discussion and using it as a method of checking the students' understanding of this concept.

Biology File: Web Link

Student Textbook page 630

There are a number of web sites that discuss the race for the double helix, or the key but unacknowledged role played by Rosalind Frankin. By comparing the accounts of the different scientists involved in the discovery of DNA, students will gain an appreciation of the human side of science.

Answers to Questions for Comprehension

Student Textbook page 630

Q6. A gene is defined as a functional sub-unit of DNA that directs the production of one or more polypeptides (protein molecules). The genome of an organism is the sum of all of the DNA that is carried in each cell of the organism.

Biology File: Try This

Student Textbook page 631

Student research may yield practical applications of comparing genomes including:

- "The genomes of related species exhibit conservation of gene order and conservation of gene sequence because the genomes of present day species have evolved from common ancestral genomes. Comparative genomics enables the application of information gained from intensely studied model systems to related organisms that are important for human health and agriculture." (Agriculture and Agri-Food Canada)
- "From bacteria to elephants, from flowers to humans, all living things follow instructions written in the universal language of DNA. All living things contain similar building blocks—proteins encoded by DNA, and all diseases can be traced back to malfunctioning genes or proteins.
  The four model organisms—yeast, worm, fly, and mouse— share vast numbers of genes, proteins, and even genetic pathways with humans. For example, flies don't get kidney disease, and worms don't get heart disease, yet many of the human genes that are faulty in these and other human disorders have parallel genes in model organisms, where they can be studied more easily." (Howard Hughes Medical Institute)
- "We can reconstruct the evolutionary history of the human genome—both the origins of interspecies differences and the presence of short segments in the human genome that have been extremely well-conserved throughout many millions of years of evolution. These highly conserved regions are thought to contain the most functionally important elements of the genome. They point to areas where intensified study will lead to a better understanding of how the genome works." (Comparative Genomics at UCSC Genome Bioinformatics Group)

Biology File: Web Link

Student Textbook page 631

There are three possible ways for DNA molecules to replicate—each obeys the rules of complementary base pairing (A-T; C-G).

- Conservative replication would leave the original DNA molecule intact and generate a completely new molecule.
- Dispersive replication would produce two DNA molecules, with sections of both old and new DNA interspersed along each strand.
- Semi-conservative replication of DNA would produce molecules with both old and new strands of DNA. Each new DNA molecule would be composed of one old strand and one new one.
  Scientists found that the replication of DNA follows the semi-conservative model. One experiment proving the semi-conservative model was conducted by Meselson and Stahl. Nitrogen, the main component of nucleotides,

occurs naturally as two isotopes, the lighter, common ^{14}N isotope, and the heavier ^{15}N isotope. In their experiment, the scientists grew *E.coli* cultures for several generations in a medium that contained only the ^{15}N isotope. When this stage of growth was completed, the DNA consisted of the ^{15}N isotope only. This DNA was now one percent heavier than normal DNA, which contains the lighter isotope. This heavier DNA was next grown for one generation in a medium that contained only the ^{14}N isotope.

They hypothesized that if semi-conservative replication had occurred, then each DNA molecule after replication would contain heavy nitrogen and light nitrogen, and would, therefore, have a density intermediate between the two. Conservative replication would produce one DNA molecule containing heavy nitrogen and one molecule containing light nitrogen, so there would be two different densities. Dispersive replication would produce a single intermediate density, just like semi-conservative replication. The observed density of the DNA after one round of replication was intermediate. Replication was therefore either semi-conservative or dispersive. These possibilities could be distinguished after a second round of replication. After two rounds, semi-conservative replication would produce two DNA molecules containing only light nitrogen, and two DNA molecules containing one light strand and one heavy strand. Therefore there would be two different densities: light and intermediate. Two rounds of dispersive replication would produce four DNA molecules, each of which would contain mostly light nitrogen and some heavy nitrogen. There would be a single density. When density of the DNA was measured after two rounds, two densities were observed: light and intermediate, indicating that DNA replication is semi-conservative, and not dispersive or conservative.

Answers to Questions for Comprehension

Student Textbook page 632

Q7. Semi-conservative replication of DNA means that each strand of DNA serves as a template for a new, complementary strand, resulting in two new DNA molecules that each contain the original parent DNA and one new strand. Each new DNA molecule thus conserves half of the original molecule.

Q8. Replication takes place in a slightly different way on each DNA strand because DNA polymerase can only catalyze elongation in the 5′ to 3′ direction. In order for both strands of DNA to be synthesized simultaneously, the method of replication must differ.

Q9. During DNA synthesis, the overall direction of elongation is the same along both strands, but elongation occurs differently. On the leading strand, DNA synthesis takes place along the DNA molecule in the same direction as the movement of the replication fork. On the lagging strand, DNA synthesis proceeds in the opposite direction to the movement of the replication fork: The lagging strand is synthesized in short fragments called Okazaki fragments.

Q10. The replication machine consists of the complex of polypeptides and DNA that interact at the replication fork. These polypeptides include DNA polymerase, an enzyme that joins nucleotides together to create a complementary strand of DNA (elongation); DNA ligase, an enzyme that splices together Okazaki fragments; primase, an enzyme that constructs the RNA primer needed for replication to begin; and helicases, a group of enzymes that cleave and unravel a segment of the double helix to enable replication. Several other proteins and enzymes are also part of the replication machine.

Biology File: Try This

Student Textbook page 633

Gene mapping refers to the mapping of genes to specific locations on chromosomes. It is a critical step in the understanding of genetic diseases. Genetic mapping uses linkage analysis (crossing over) to determine the relative position between two genes on a chromosome.

DNA sequence maps are also a kind of gene map. A DNA map shows the sequence of nucleotides along a gene or a chromosome.

Investigation 18.A: Modelling DNA Structure and Replication

Student Textbook page 634

Purpose

The purpose of this investigation is for students to design a working model of a short strand of DNA that can be used to simulate the molecular structure of DNA and the process of DNA replication.

Outcomes

- 30–C3.2s
- 30–C3.4s

Advance Preparation

When to Begin	What to Do
4 or 5 days before	■ Allow students to meet to plan the design of their model and the materials that they will need to bring
1 to 2 days before	■ Photocopy **BLM 18.1.9 (HAND) Investigation 18.A: Modelling DNA Structure and Replication.**

Section 18.1 Review Answers

Student Textbook page 635

1. Several answers are possible. Experiments are described below in date order.

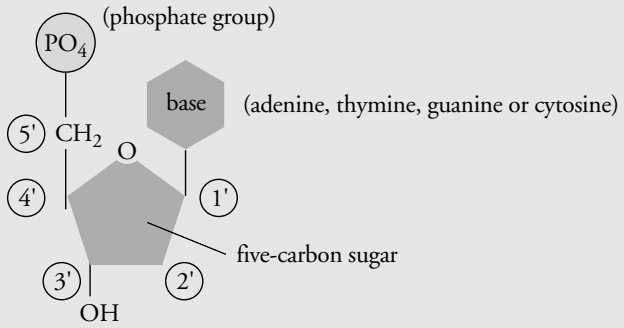
- In 1928, Frederick Griffith studied *Streptococcus pnemoniae,* a pathogenic bacterium that was responsible for pneumonia. Griffith used dead bacteria as a control. The dead pathogenic bacteria had passed on their disease-causing properties to live, non-pathogenic bacteria. Griffith called this phenomenon the transforming principle, because something from the heat-killed pathogenic bacteria must have transformed the living non-pathogenic bacteria to make them disease-causing.
- In 1944, Oswald Avery, Colin MacLeod, and Maclyn McCarty conducted a series of experiments and discovered:
  - When they treated heat-killed pathogenic bacteria with a protein-destroying enzyme, transformation still occurred.
  - When they treated heat-killed pathogenic bacteria with a DNA-destroying enzyme, transformation did not occur. These results provided evidence for DNA's role in transformation.
- Alfred Hershey and Martha Chase used radioactive labelling to show that genes are made of DNA. Hershey and Chase used a strain of virus known as a T2 bacteriophage, which consists of a protein coat surrounding a length of DNA. This virus attaches to a bacterial cell and injects genetic information into the cell. The infected cell manufactures new viruses, and then it bursts. The newly released viruses go on to infect other cells. To determine whether viral protein or viral DNA was responsible for taking over the genetic machinery of the host cell, Hershey and Chase produced two batches of the virus. In one batch, they labelled the protein coat using radioactive sulfur. In the other batch, they labelled the DNA with radioactive phosphorus. The labelled viruses were allowed to infect bacterial cells. The cells were then agitated in a blender to separate the viral coats from the bacterial cells. Each medium was tested for radioactivity. The results demonstrated that viral DNA, not viral protein, enters the bacterial cell.

2. (a) While studying DNA in the early 1900s, Phoebus Levene reported that the nucleotides were present in equal amounts, and that they appeared in chains in a constant and repeated sequence of nitrogen bases. Therefore, most scientists thought that the great variety of proteins was an important factor, and must be the hereditary material. Scientists assumed that the molecular structure of DNA was just too simple to provide the great variation in inherited traits.

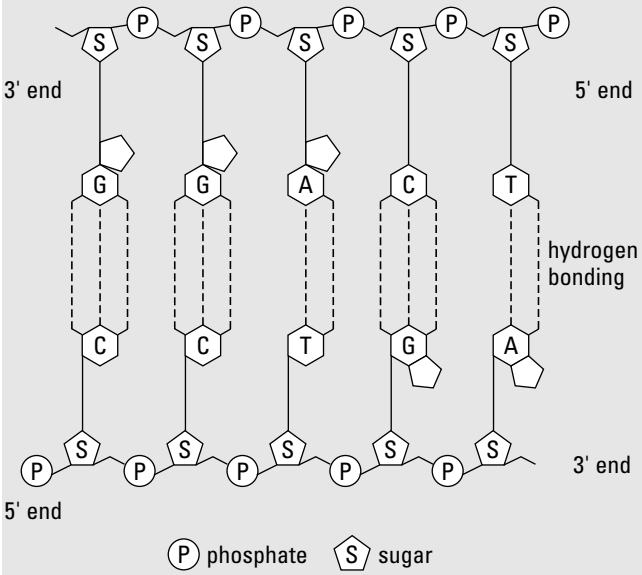
(b) In 1944, Oswald Avery, Colin MacLeod, and Maclyn McCarty conducted a series of experiments and discovered:

- When they treated heat-killed pathogenic bacteria with a protein-destroying enzyme, transformation still occurred.
- When they treated heat-killed pathogenic bacteria with a DNA-destroying enzyme, transformation did not occur. These results provided evidence that genetic information was carried on DNA.

3.



4.



5. In Linus Pauling's model, DNA replication would have to occur without nitrogen base pairing. Student answers may provide other possible differences. Accept any well-reasoned answer.

6. Sample B is the viral DNA because the percentages of adenine and thymine are not the same, and similarly the percentages of guanine and cytosine are not the same, as they are in sample A, which shows complementary base pairing of these respective bases. Complementary base parring does not occur in a single-stranded DNA virus.

7.

Characteristic	DNA	RNA
Strands	Double stranded	Single stranded, but may fold on back itself
Phosphate	PO_4	PO_4
5-Carbon Sugar	Deoxyribose sugar	Ribose sugar
Nitrogen bases	Adenine-Thymine Guanine-Cytosine (only DNA has thymine)	Adenine-Uracil Guanine-Cytosine (only RNA has uracil)
Forms	One type of DNA	Three types of RNA
Location	Only in the nucleus and mitochondria of eukaryotes; also found in bacteria	In the nucleus, mitochondria, and cytoplasm of eukaryotes; also found in bacteria

8. In the semi-conservative replication of the double-stranded DNA, each new molecule of DNA contains one strand of the original DNA molecule and one new strand made from nucleotides. Thus, each new DNA molecule conserves half of the original molecule.

9. The steps involved in the synthesis of the DNA molecule are as follows: Replication begins with a specific nucleotide sequence called the replication origin. A eukaryotic cell may contain thousands of these sequences, while the chromosome of a prokaryote has only a single replication origin. A group of enzymes, called the helicases, bind to the DNA at each replication origin. The helicases cleave and unravel a section of the original double helix, creating Y-shaped areas (replication forks) at the end of the unwound areas, which form a replication bubble. These single strands serve as templates for the semi-conservative replication of DNA. New DNA strands are produced when an enzyme called DNA polymerase inserts into the replication bubble. A primase enzyme synthesizes an RNA primer that serves as the starting point of new nucleotide attachment by DNA polymerase. DNA polymerase can only synthesize the new nucleotide chain in the 5′ to 3′ direction. As a result, one strand (the leading strand) is replicated continuously in the 5′ to 3′ direction in the same direction that the replication fork is moving. The other strand, known as the lagging strand, is replicated in short segments, still in the 5′ to 3′ direction, but away from the replication fork. These fragments, called Okazaki fragments, are spliced together by DNA ligase. When replication is complete, DNA polymerase dismantles the RNA primer and proofreads the nitrogen base pairing of the two new DNA molecules. Each new molecule of DNA contains one parent strand and one new strand.

10. The object of Human Genome Project was to determine the sequence of nitrogen bases for the DNA in the chromosomes of the entire human genome. The Human Genome Project is an important step in understanding how genes determine our genetic characteristics. This understanding can be applied to medical genetics and the treatment of disease, as well as to other sciences.

18.2 Protein Synthesis and Gene Expression

Student Textbook pages 636–642

Section Outcomes

Students will:

- explain how genetic information is encoded in DNA molecules
- describe the processes through which genetic information is expressed in living cells
- design and perform a simulation to illustrate the steps of protein synthesis

Key Terms

amino acids
genetic code
gene expression
transcription
messenger RNA (mRNA)
transfer RNA (tRNA)
translation
codon
RNA polymerase
promoter
anticodon
ribosomal RNA (rRNA)
genomics
proteomics

Biology Background

- In addition to RNA polymerase, several different proteins also initiate the process of translation. To initiate translation, one of these proteins binds to a specific nucleotide sequence TATAAA (known as the TATA box) on the DNA, enabling transcription to begin. Usually, transcription begins about 35 base pairs downstream from the TATA box.
- Translation always begins at the mRNA start codon AUG, which codes for methionine. When mRNA binds to the ribosome, a specific tRNA with the anticodon UAC recognizes the AUG codon and carries a special form of methionine, called N-formylmethionine, to the ribosome. The tRNA binds to the mRNA and ribosome, and

translation begins. Translation is terminated when the ribosome reaches one or more of the stop codons UAA, UAG, or UGA. Often, two stop codons will be found together on the mRNA.

Teaching Strategies

- Introduce this section with **BLM 18.2.1 (OH) The Central Dogma**.
- Use **BLM 18.2.2 (OH) mRNA** to help students compare the structure and function of mRNA to DNA. Review the specific roles carried out by the different forms of RNA (mRNA, tRNA, and rRNA) in transcription and translation.
- **BLM 18.2.4 (OH) Transcription** provides students with a model of the first step in the synthesis of a protein. Use this overhead with **BLM 18.2.3 (OH) Table: Messenger RNA Codons and Their Corresponding Amino Acids**. This BLM can also be photocopied and distributed to students to keep as a reference in their notebooks.
- Use **BLM 18.2.7 (OH) Protein Structure** to review amino acids, peptide bonds, and the primary structure of a protein molecule.
- **BLM 18.2.8 (OH) The Translation Cycle** provides students with a model that illustrates how a protein is assembled. Review this model with students, asking individual students to describe the different steps to the class. If a student gets stuck, he or she can ask for assistance from the other students.
- To illustrate how the structure and function of tRNA differs from that of DNA and mRNA, use **BLM 18.2.5 (OH) tRNA**. Ask students to explain how the structure of tRNA enables it to carry out its specific role in translation.
- **BLM 18.2.9 (HAND) Transcription and Translation Worksheet** provides students with extra transcription and translation practice questions, while **BLM 18.2.11 (OH) Gene Expression** summarizes the processes of transcription, translation, and protein formation.

SUPPORTING DIVERSE STUDENT NEEDS

- The interactive nature of many web sites could help students visualize the steps involved in the synthesis of a protein. Web links can be found at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links.
- Advanced students with skills in computer animation could be encouraged to build an animation of this process to help other students in the class understand how a protein is synthesized.

Answers to Questions for Comprehension

Student Textbook page 636

Q11. The structure of a protein is determined by the structure of the DNA molecule. The order of the base pairs in a DNA molecule makes up the genetic code of an organism. The genetic code determines how the amino acids are strung together and how the proteins are made. In other words, the order of the nucleotides in the gene provides the information—written in genetic code—that is necessary to build a protein.

Q12. The two basic steps in gene expression are:

Step 1: The DNA is copied onto an RNA molecule in a process called transcription. In a eukaryotic cell, transcription takes place in the nucleus.

Step 2: The RNA molecule then moves to the cytoplasm of the cell, where the RNA nucleotide sequence directs the synthesis of a protein. This process is called translation.

Student Textbook page 637

Q13. Three bases make up each mRNA codon.

Q14. The characteristics of the genetic code:

(a) A redundant genetic code means that more than one codon can code for the same amino acid.

(b) A continuous genetic code means that the code reads as a continuous series of three-letter codons without spaces, punctuation, or overlap.

(c) A universal genetic code means that almost all living things use the same genetic code to build proteins.

Answers to Practice Problems

Student Textbook page 637

3. Problem

Use Table 18.3 to find the amino acid that corresponds to each of the following codons.

a) CCA **b**) AUG **c)** GCA

What Is Required?

You must determine the amino acid that corresponds to each of the codons CCA, AUG, and GCA.

What Is Given?

You are provided with the codons CCA, AUG, and GCA.

You have Table 18.3, which provides the messenger RNA codons and their corresponding amino acids.

Plan Your Strategy

Use Table 18.3 to identify the amino acid that corresponds to each codon.

Act on Your Strategy

Step 1 To determine the amino acid that corresponds to the codon CCA, find the first base, C, in the left hand column of the table titled "First base." To find the second base, C, read across the rows in the "Second base" column at the top of the table. Where the first base row and the second base column meet, you will find a list of four possible amino acids. To determine the correct amino acid, read down the column titled "Third base" to find the last base, A, of the codon, which will identify the amino acid *proline* as corresponding to the codon CCA.

Step 2 To determine the amino acid that corresponds to the codon AUG, repeat the process you carried out in step 1, using the bases in the AUG codon. The amino acid *methionine* corresponds to the codon AUG.

Step 3 To determine the amino acid that corresponds to the codon GCA, repeat the process you carried out in the previous steps, using the bases in the GCA codon. The amino acid *alanine* corresponds to the codon GCA.

Check Your Solution

Repeating the strategy provides the same results.

4. Problem

What three RNA codons serve as "stop" signals?

What Is Required?

You must determine the three codons that serve as stop signals.

What Is Given?

You have Table 18.3, which provides the messenger RNA codons and their corresponding amino acids.

Plan Your Strategy

Use Table 18.3 to identify the three codons that represent stop codons.

Act on Your Strategy

Step 1 To determine the three codons that represent stop codons, scan the amino acids listed in the centre of Table 18.3. The codons UAA, UAG, and UGA are identified as stop codons in the table.

Check Your Solution

Repeating the strategy provides the same results.

5. Problem

Write three different codons that correspond to the amino acid arginine.

What Is Required?

You must determine three codons that correspond to the amino acid arginine.

What Is Given?

You have Table 18.3, which provides the messenger RNA codons and their corresponding amino acids.

Plan Your Strategy

Use Table 18.3 to identify three codons that correspond to the amino acid arginine.

Act on Your Strategy

Step 1 To determine three codons that correspond to the amino acid arginine, scan the amino acids listed in the centre of Table 18.3. The codons CGU, CGC, CGA, CGG, AGA, and AGG all represent the amino acid arginine. List any three of these codons to answer the question correctly.

Check Your Solution

Repeating the strategy provides the same results.

Student Textbook page 638

6. Problem

An mRNA strand contains the following nucleotide sequence: AUGCCCACUACAUAG. What amino acid sequence does this mRNA code for?

What Is Required?

You need to determine the amino acid sequence that the mRNA nucleotide sequence AUGCCCACUACAUAG codes for.

What Is Given?

You are provided with the mRNA nucleotide sequence AUGCCCACUACAUAG.

You have Table 18.3, which provides the messenger RNA codons and their corresponding amino acids.

Plan Your Strategy

Divide the nucleotide sequence into codons of three nucleotides each.

Use Table 18.3 to identify the amino acid that corresponds to each codon in the mRNA nucleotide sequence.

Write the amino acids in the sequence that corresponds to the mRNA nucleotide sequence given.

Act on Your Strategy

Step 1 Dividing the nucleotide sequence into codons of three nucleotides each provides the following sequence: AUG-CCC-ACU-ACA-UAG

Step 2 To determine the amino acid that corresponds to the codon AUG, find the first base, A, in the left hand column of the table titled "First base." To find the second base, U, read across the rows in the "Second base" column at the top of the table. Where the first base row and the second base column meet, you will find a list of four possible amino acids. To determine the correct amino acid, read down the column titled "Third base" to find the last base, G, of the codon, which will identify the amino acid *methionine* as corresponding to the codon AUG.

Step 3 To determine the amino acid that corresponds to the codon CCC, repeat the process you carried out in step 2, using the bases in the CCC codon. The amino acid *proline* corresponds to the codon CCC.

Step 4 Repeat the above steps for the codons ACU and ACA. These codons each correspond to the amino acid *threonine*.

Step 5 To determine the amino acid that corresponds to the codon UAG, repeat the process you carried out in the previous steps, using the bases in the UAG codon. This will identify the codon UAG as a *stop* codon with no corresponding amino acid.

Step 6 To determine the amino acid sequence that the mRNA sequence codes for, write the amino acids you determined by using Table 18.3 in the order

corresponding to the mRNA sequence. The amino acid sequence that the mRNA sequence AUGCCCACUACAUAG codes for is *methionine-proline-threonine-threonine.*

Check Your Solution

Repeating the strategy provides the same results.

7. Problem

A DNA strand contains the following nucleotide sequence: TACTGCCTCCCCATAAGAATT.

(a) What is the nucleotide sequence of the mRNA strand that is transcribed from this DNA template?

(b) What is the amino acid sequence of the polypeptide that is produced from this mRNA strand?

What Is Required?

You must determine the nucleotide sequence of the mRNA strand that is transcribed from this DNA template.

You then need to determine the amino acid sequence of the polypeptide that is produced from this mRNA strand.

What Is Given?

You are provided with the DNA nucleotide sequence TACTGCCTCCCCATAAGAATT.

You have Table 18.3, which provides the messenger RNA codons and their corresponding amino acids.

Plan Your Strategy

Use your knowledge of nucleotide pairing to determine the nucleotide sequence of the mRNA strand that is transcribed from this DNA template.

Divide the mRNA nucleotide sequence into codons of three nucleotides each.

Use Table 18.3 to identify the amino acid that corresponds to each codon in the mRNA nucleotide sequence.

Write the amino acids in the sequence that corresponds to the mRNA nucleotide sequence given.

Act on Your Strategy

Step 1 You know that the nucleotides A, T, C, and G in a strand of DNA correspond to the nucleotides U, A, G, and C in a strand of mRNA, respectively. The nucleotide sequence of the mRNA strand that is transcribed from the DNA nucleotide sequence of TACTGCCTCCCCATAAGAATT is as follows: AUGACGGAGGGGUAUUCUUAA

Step 2 Dividing the nucleotide sequence into codons of three nucleotides each provides the following sequence: AUG-ACG-GAG-GGG-UAU-UCU-UAA

Step 3 To determine the amino acid that corresponds to the codon AUG, find the first base, A, in the left hand column of the table titled "First base." To find the second base, U, read across the rows in the "Second base" column at the top of the table. Where the first base row and the second base column meet, you will find a list of four possible amino acids. To determine the correct amino acid, read down the column titled "Third base" to find the last base, G, of the codon, which will identify the amino acid *methionine* as corresponding to the codon AUG.

Step 4 To determine the amino acid that corresponds to the codon ACG, repeat the process you carried out in step 3, using the bases in the ACG codon. The amino acid *threonine* corresponds to the codon ACG.

Step 5 Repeat the above steps for the codons GAG, GGG, UAU, and UCU. These codons correspond to the amino acids *glutamate, glycine, tyrosine*, and *serine,* respectively.

Step 6 To determine the amino acid that corresponds to the codon UAA, repeat the process you carried out in the previous steps, using the bases in the UAA codon. This will identify the codon UAA as a *stop* codon with no corresponding amino acid.

Step 7 To determine the amino acid sequence that the mRNA sequence codes for, write the amino acids you determined by using Table 18.3 in the order corresponding to the mRNA sequence. The amino acid sequence that the mRNA sequence AUGACGGAGGGGUAUUCUUAA codes for is *methionine-threonine-glutamate-glycine-tyrosine-serine.*

Check Your Solution

Repeating the strategy provides the same results.

Thought Lab 18.2: Transcription in Reverse

Student Textbook page 639

Purpose

The purpose of this investigation is to reinforce the concept of redundancy (degeneracy) of the genetic code and to perform a simulation to demonstrate the tranocription of a stretch of DNA.

Outcomes

- 30–C3.2s

Advance Preparation

When to Begin	What to Do
1-2 days before	■ Photocopy **BLM 18.2.6 (HAND) Thought Lab 18.2: Transcription in Reverse.**

Time Required

Approximate time required is 15 to 20 minutes

Helpful Tips

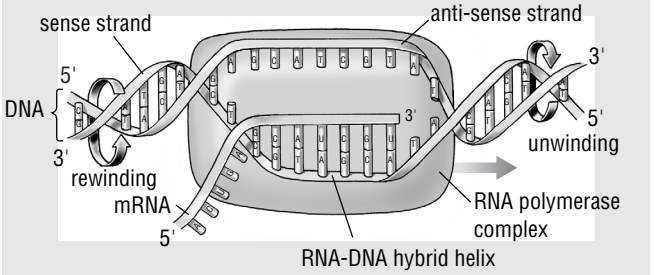
- Use B**LM 18.2.6 (HAND) Thought Lab 18.2: Transcription in Reverse** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 18.2.6A (ANS) Thought Lab 18.2: Transcription in Reverse Answer Key.**
- Discuss the concept of redundancy (degeneracy) of the genetic code, and ask students to consider how it will affect their answers to the lab questions.
- Review transcription and translation of the genetic code. Review how to read Table 18.3 Messenger RNA Codons and Their Corresponding Amino Acids.
- Challenge students to determine how many different codes could code for this polypeptide.
- Remind students that a RNA molecule does not have thymine nucleotides—they are replaced by uracil.
- The abbreviation ASP refers to the amino acid aspartate, while ASN is the abbreviation for the amino acid asparagine.
- Students will have to determine the mRNA codon for each amino acid first. Then they will be able to figure out the DNA genetic code.

Answers to Procedure Questions

1. The following outlines one possible nucleotide sequence for the DNA molecule that contains the genes for this polypeptide.

Amino acid	mRNA codon	DNA genetic code
met	AUG	TAC
lys	AAA	TTT
asp	GAU	CTA
asp	GAC	CTG
val	GUU	CAA
leu	CUU	GAA
leu	CUC	GAG
phe	UUU	AAA
leu	CUA	GAT
ala	GCU	CGA
glu	CAA	GTT

2.



Answers to Analysis Questions

1. Student answers should indicate that the genetic code is redundant—that is, more than one codon can code for the same amino acid. Only three codons do not code for any amino acid. The redundancy in the genetic code is extremely valuable to the organism. For example, if a mutation occurs to the DNA and an AAT sequence becomes AAC, the messenger RNA codon transcribed by the original DNA is UUA while the mutated DNA transcribes a UUG codon. The mutation, however, will not be deleterious to the organism because these two codons correspond to the same amino acid—leucine.

2. It is advantageous for the cell to keep its DNA inside the nucleus rather than have it move from the nucleus to the ribosomes in the cytoplasm. This reduces the chances of a mutation (damage) occurring to the DNA during this process. As well, if the DNA stays inside the nucleus, only the gene required to synthesize the protein has to be exposed. Once again, this reduces the chances of the DNA being damaged.

Assessment Options

- Collect students' answers to the Procedure and Analysis questions.
- Consider doing this activity as a class discussion using formative assessment techniques instead of more summative techniques to assess student understanding.

Answers to Questions for Comprehension

Student Textbook page 640

Q15. The RNA polymerase complex catalyzes the synthesis of mRNA during transcription. The RNA polymerase complex recognizes the promoter region (specific nucleotide sequence) on the DNA molecule and binds to the sense strand of the DNA. It then opens a section of the double helix and synthesizes a strand of mRNA that is complementary to the sense strand of DNA, replacing the base thymine with uracil as it does so. Synthesis of the new mRNA strand is always in the 5′ to 3′ direction, adding each new nucleotide to the 3′-OH group of the previous nucleotide. When the RNA

polymerase complex reaches a signal to stop transcription (a specific nucleotide sequence in the DNA template), it detaches from the sense strand. The new mRNA strand also detaches from the RNA polymerase complex and the DNA double helix reforms.

Q16. Transfer RNA is a single strand of RNA that is folded into a lobular shape. One lobe contains an anticodon, a stretch of three nucleotides that is complementary to an mRNA codon. At the opposite end of the molecule is a binding site for the amino acid that corresponds to the codon. During translation, the tRNA molecules carry specific amino acids to the ribosomes where proteins are assembled. Each tRNA codon pairs with its matching mRNA codon at the ribosome and the amino acid it carries is transferred to the growing polypeptide chain.

Investigation 18.B: Simulating Protein Synthesis

Student Textbook page 641

Purpose

The purpose of this investigation is to use a model to simulate the processes of transcription and translation.

Outcomes

- 30–C3.1s
- 30–C3.2s
- 30–C3.4s

Advance Preparation

When to Begin	What to Do
3 to 4 days before	■ Allow students to get together for 15 minutes for a planning session
1 to 2 days before	■ Photocopy **BLM 18.2.10 (HAND) Investigation 18.B: Simulating Protein Synthesis.**

Materials
■ Materials will depend on individual model designs.

Time Required

- 15 to 20 minutes for planning
- 50 to 60 minutes for the activity

Helpful Tips

- Use **BLM 18.2.10 (HAND) Investigation 18.B: Simulating Protein Synthesis** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 18.2.10A (ANS) Investigation 18.B: Simulating Protein Synthesis Answer Key.**
- A few days before carrying out the investigation, give the student groups 15 to 20 minutes to do some advanced planning so they can accumulate materials that they might want to use.
- There are model kits available that can be used in this investigation. The use of models will speed up the planning process, but will reduce the variety of student models.
- Design your own marking rubric to assess student models or use one similar to the rubric provided in the Assessment Options below.

Safety Precautions

- If students use food products for their models, remind them not to eat anything from the science lab. Also remind students of potential food allergies.

Answers to Analysis Questions

1. Accept any well-reasoned answers that make specific reference to the simulations presented by other groups.

2. The mRNA codons UAA, UAG and UGA are stop codons. The ribosome moves along the mRNA molecule during the translation cycle until it reaches a stop codon. It then releases the polypeptide and the ribosome assembly comes apart, ending the translation cycle.

Answer to Conclusion Question

3. Advantages of simulating molecular processes: A model or simulation may help clarify the steps in a complex process, may allow scientists to envision processes involving relatively small molecules, and may enable scientists to communicate their ideas to other scientists or the general public.

Disadvantages of simulating molecular processes: Use of models may reinforce misconceptions (i.e., electrons orbit the nucleus like planets orbit the Sun) and may not actually represent the molecular processes they intend to simulate or the structures involved.

Effective simulations may be characterized by an accurate and realistic depiction of structures involved in the modelled process, careful analysis of the sequence of steps involved, and choice of a medium or form that can be clearly understood by others considering the model.

Assessment Options

- Collect and assess students' answers to Analysis and Conclusion questions.
- Use a simple rubric to evaluate student models. An example of a rubric is shown below:

- **Three points:** designed and constructed their model completely and accurately; were able to identify each part of the model; and, actively participated in the class discussion about protein synthesis.
- **Two points:** designed and constructed their model but had a couple of errors; were able to identify most parts of the model; and, participated somewhat in the class discussion.
- **One point:** designed but were unable to complete their model; they were able to identify some parts of the model; and participated a little in the class discussion.

- To assess group performance, use Assessment Checklist 3 Performance Task Self-Assessment and/or Assessment Checklist 4 Performance Task Group Assessment (See Appendix A).

Section 18.2 Review Answers

Student Textbook page 642

1. The "central dogma" describes how genetic information in DNA is used to make RNA, and how RNA then directs the synthesis of proteins. Transcription is when the sequence of nitrogen bases in DNA is "transcribed" to make RNA. The RNA directs the sequential assembly of amino acids into a chain called a polypeptide, or a protein, in a process called translation.

2. The amino acid that corresponds to each of the mRNA codons is

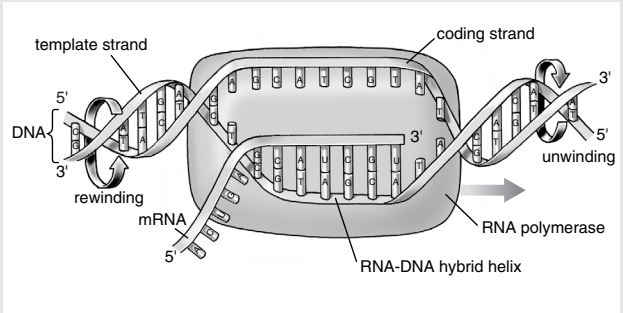
(a) UCC – serine **(b)** ACG – threonine

(c) GUG – valine **(d)** CAC – histidine

3. The codons that code for serine are UCU, UCC, UCA, UCG, AGU, and AGC.

4. Almost all living organisms have the same genetic code. A gene that is taken from one species and inserted into another will produce the same protein.

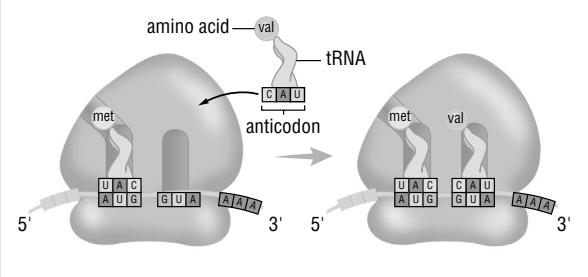
5. Student diagrams should resemble Figure 18.13, which illustrates the process of transcription.



6. Because DNA is double stranded, DNA polymerase is able to recognize whether hydrogen bonding is taking place between a base in the newly synthesized strand of DNA and its complement in the original strand. The absence of hydrogen bonding indicates a mismatch between bases, and DNA polymerase excises the incorrect base and inserts the correct one. This proofreading ability reduces the incidence of mutation in the genetic code and the possible translation of a nonfunctional protein. Other suggestions may be provided. Accept any reasonable answer.

7. The ribosomes provide the machinery for translation. Ribosomes are located both freely in the cytoplasm, and bound to the endoplasmic reticulum.

8.



- Translation is activated when an mRNA molecule binds to an active ribosome complex. The mRNA binds in such a way that two adjacent codons are exposed. The first tRNA molecule carrying the amino acid methonine temporarily bonds with the exposed mRNA start codon. Once the tRNA and mRNA are in place, translation follows a cycle of three steps:
- A second "loaded" tRNA molecule arrives at the codon adjacent to the first tRNA.
- Enzymes catalyze the formation of a peptide bond that joins the amino acid carried by the first tRNA to the amino acid carried by the second tRNA. At the same time, the amino acid chain is transferred from the first tRNA to the second tRNA.
- The ribosome moves a distance of one codon along the mRNA strand. The first tRNA molecule detaches from the mRNA, and picks up another amino acid. The second tRNA now holds a growing amino acid chain. A third tRNA molecule arrives at the newly-exposed codon next to the second tRNA, and the cycle repeats.

9. Ribosomal RNA (rRNA) is found in the ribosomes, which is where the messenger RNA (mRNA) is read and the amino acids are assembled to form a polypeptide. Messenger RNA (mRNA) transcribes the genes—the sequence of nitrogen bases in a strand of DNA—and carries this "message" from the DNA in the nucleus to the ribosomes in the cytoplasm. Transfer RNAs (tRNA) in the cytoplasm bond to individual amino acids and take them to the complementary codons of the mRNA at the binding site on the ribosome, where a growing polypeptide chain is built.

10. (a) In a eukaryotic cell transcription occurs in the nucleus and translation occurs in the cytoplasm. In a bacterial cell, the DNA is in the cytoplasm; there is no nucleus.

(b) The main advantage is that protein synthesis can occur faster because the mRNA does not have to leave the nucleus as it does in a eukaryotic cell. A possible disadvantage is that in bacterial cells, DNA is not protected by a a nucleus and the chance of DNA mutation may be increased.

18.3 Mutations and Genetic Recombination

Student Textbook pages 643–651

Section Outcomes

Students will:

- explain some of the causes and effects of DNA mutations
- describe how random changes in nucleotide sequences provide a source of genetic variability
- explain how nucleotide sequences provide evidence that different species of organisms are related
- design and perform a simulation to illustrate the use of restriction enzymes and ligases to create recombinant DNA

Key Terms

mutation
somatic cell mutation
germ line mutation
point mutation
silent mutation
mis-sense mutation
nonsense mutation
frameshift mutation
mutagen
physical mutagen
chemical mutagen
carcinogenic
mitochondrial DNA (mtDNA)
genetic engineering
recombinant DNA
restriction enzyme
restriction endonuclease
restriction fragment
gel electrophoresis
DNA fingerprint

Biology Background

- Numerous human diseases result from chromosomal mutations. Sickle-cell disease is the result of a mis-sense mutation in which the adenosine at the 17th nucleotide in the gene that codes for the beta chain of hemoglobin is substituted with thymine. As result, the codon GAG, which codes for glutamic acid, is changed to GTG, which codes for valine. Subsequently, a slightly altered but still functional protein results. Frameshift mutations due to insertions or deletions that alter the entire reading frame of a nucleotide sequence also account for numerous diseases. For example, both Huntington's disease and fragile X syndrome result from the insertion of a trinucleotide repeat into the reading frame.
- The TP53 is a gene that codes for p53, a transcription factor that is involved in cell cycle regulation. (53 refers to the molecular mass of the protein.) Because of its regulatory function, it is also a tumour suppressor gene. The transcription factor carries out many important anti-cancer regulatory functions. It induces apoptosis and cell senescence, and also activates DNA repair proteins. If the TP53 gene becomes mutated, the cell's tumour suppression abilities may be severely hindered, resulting in an increased incidence of cancer. In humans, TP53 is located on chromosome 17.
- Transposons, also known as jumping genes or mobile genetic elements, are nucleotide sequences that can move within the genome of a cell. Transposons can move within the gemome in two ways. Class I transposons are first transcribed into RNA and then back into DNA (as a result they are often called retrotransposons), while Class II transposons are able to change position within the genome with the help of the enzyme transposase, which inserts and cuts these DNA sequences directly. Transposons were discovered in maize DNA by botanist Barbara McClintock in the 1950s, at which time her research was greeted with what she referred to as "puzzlement, even hostility" from other scientists who were skeptical of her findings. When the process was recognized in bacteria and yeast in the 1960s, she finally received credit for her earlier discoveries. In 1983, she was awarded the Nobel Prize for discovering "mobile genetic elements," three decades after the fact.

Teaching Strategies

- Use **BLM 18.3.1 (OH) Mutations** to reinforce information on silent, mis-sense, nonsense, and frameshift mutations. Use this BLM as an overhead to help illustrate these mutations or photocopy and have students include it in their notebook for reference. **BLM 18.3.2 (HAND) Mutations Worksheet** provides students with extra mutation problems to solve as take-home homework or as an in class exercise in which students work individually or in partners.
- Use **BLM 18.3.4 (HAND) Prevention of Cancer** and **BLM 18.3.5 (HAND) FAQ – Tobacco and Health** to supplement the information for Thought Lab 18.3: Investigating Cancer Genes. Invite an expert from the Canadian Lung Association in to speak to your students about the dangers of smoking (tobacco use) and cancer. Make sure that your speaker is prepared to speak at a Biology 30 level, and uses terminology such as oncogenes, tumour suppressor genes, stability genes, and p53 gene.
- **BLM 18.3.6 (HAND) Restriction Endonucleases** is a worksheet style BLM that students can use to fill in details with regards to how these enzymes work. In addition to providing answers to this worksheet, **BLM 18.3.6A**

(ANS/OH) Restriction Endonucleases Answer Key can also be used as an overhead to support a class discussion on recombinant DNA.

- **BLM 18.3.8 (HAND) Cohen-Boyer Experiment** provides supplemental information to support Thought Lab 18.4: Recreating the First Chimera. This BLM also includes a diagram outlining the process followed by Cohen and Boyer similar to that shown in the textbook. Photocopy and have students read this BLM prior to starting the Thought Lab. An excellent animation of the Cohen-Boyer experiment can be accessed at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links.
- **BLM 18.3.9 (OH) Gel Electrophoresis** is very similar to Figure 18.19 in the textbook. Use this BLM as an overhead to help illustrate gel electrophoresis or photocopy and have students include it in their notebook for reference.
- There are several web sites that host animations showing the steps involved in gel electrophoresis that can help students to visualize this process more clearly. An excellent animation can be accessed at **www.albertabiology.ca**, Online Learning Centre, Instructor Edition, Teacher Web Links.
- **BLM 18.3.11 (HAND) DNA Fingerprinting** provides students with more information regarding this technology. This worksheet style BLM also supports Thought Lab 18.5: Reading a DNA Fingerprint and shows a larger image of the southern blot shown on page 651 of student text.

Answers to Questions for Comprehension

Student Textbook page 644

Q17. The redundancy of the genetic code protects a cell from the effects of substitution mutations. A change in the coding sequence of a gene does not always result in a change to the polypeptide product of a gene.

Q18. The insertion or deletion of one or two nucleotides results in a frameshift mutation. A frameshift mutation causes the entire reading frame of the gene to be altered. A shift in the reading frame usually results in a nonsense mutation.

Q19. A frameshift mutation is more likely to have serious consequences for a cell than a substitution mutation because the frameshift mutation causes the entire reading frame of the gene to be altered.

Student Textbook page 645

Q20. (a) A spontaneous mutation is a mutation that is caused by molecular interactions that take place naturally within cells. An induced mutation is caused by agents outside of the cell, such as certain factors in the environment.

(b) Physical mutagens cause changes in the structure of the DNA. High-energy radiation, such as those from x-rays and gamma rays, is the most damaging form of physical mutagen. A chemical mutagen is a molecule that can enter the nucleus of a cell and induce mutations by reacting chemically with the DNA. Examples of chemical mutagens include nitrites, gasoline fumes, and various compounds in cigarette smoke.

Thought Lab 18.3: Investigating Cancer Genes

Student Textbook page 646

Purpose

The purpose of this investigation is to determine the relationship between smoking and the genetic changes that lead to mutations and cancer.

Outcomes

- 30–C.3s

Advance Preparation

When to Begin	What to Do
5 or 6 weeks before	■ Book speakers from the Canadian Lung Association.
2 or 3 weeks before	■ Book computer lab and/or the library.
1 to 2 days before	■ Photocopy **BLM 18.3.3 (HAND) Thought Lab 18.3: Investigating Cancer Genes.** ■ Photocopy **BLM 18.3.4 (HAND): Prevention of Cancer** and **BLM 18.3.5 (HAND) : FAQ-Tobacco and Health**. ■ Photocopy Assessment Checklist 7 Independent Research Skills, in Appendix A if using.

Time Required

1 hour for research

1 hour to answer Analysis questions

Helpful Tips

- Use **BLM 18.3.3 (HAND) Thought Lab 18.3: Investigating Cancer Genes** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 18.3.3A (ANS) Thought Lab 18.3: Investigating Cancer Genes Answer Key**.

- Photocopy and distribute **BLM 18.3.4 (HAND) Prevention of Cancer** and **BLM 18.3.5 (HAND) FAQ – Tobacco and Health**. These informational BLMs can provide the context for student research.
- Photocopy and distribute Assessment Checklist 7 Independent Research Skills, found in Appendix A of this resource, if you plan to use this as part of your assessment plan for this activity. Or, you may wish to provide students with your own rubric indicating how you plan on assessing their research report.
- Unless you are using this activity to teach Internet search strategies, you can save time by providing students with a list of Internet sites to start their research on smoking and cancer.
- Arrange for a speaker from the Canadian Lung Association or from a local cancer agency who can talk to your students about the link between smoking (tobacco use) and cancer. Make sure that the speaker is prepared to discuss this from a somatic mutation point of view.

Answers to Analysis Questions

1. Key points that students should have discovered are:
- Lung cancers are strongly associated with cigarette smoking, and cigarette smoke contains a number of proven and suspected carcinogens (cancer-causing agents). In order to understand how cigarette smoke components cause lung cancer and other smoking-related cancers, it is necessary to understand the sequence of events that leads from smoke inhalation to formation of a tumour many years or decades later.
- One of the initial crucial events is most likely damage of the genetic material (DNA) by a cigarette smoke carcinogen. This damage can, under certain circumstances, be repaired by cellular DNA repair mechanisms. However, if not repaired, cells will attempt to duplicate their DNA during normal cell division, but are impeded by the damage and will carry out an error-prone duplication process leading to gene mutations (changes in the gene). Such gene mutations are then found many years later in the DNA of lung tumours.
- Gene mutations are particularly harmful if they occur in genes that control cell division rates or genetic stability. According to current thinking, a number of genes need to be mutated or functionally disabled before a normal cell loses all normal growth control mechanisms and is brought onto a path of uncontrolled cell division, eventually leading to a tumour. Gene mutations have been found in genes such as p53, *ras*, and pl6 at a relatively high frequency in human lung cancer.

2. Student answers will depend on the amount of time that you provide them to conduct their research, and the resources that are available to them.

3. Student answers will depend on their personal views on smoking. Possible tools could include multimedia programs, television commercials, computer games, posters, educational materials, or any other reasonable tool.

Assessment Options

- Collect and assess students' answers to Analysis questions.
- Use Assessment Checklist 7 Independent Research to assess the research phase of this project.
- Use your own rubric or other tool to evaluate the students' reports.

Answers to Questions for Comprehension

Student Textbook page 647

Q21. Your mitochondrial DNA is identical to the mitochondrial DNA of your mother, as the father's sperm contributes essentially no cytoplasm, and therefore no cytoplasmic organelles, to its offspring. On the other hand, your mother's egg provided most of the cytoplasm and cytoplasmic organelles, such as the mitochondria. While the DNA in the nuclei of your cells is made up of an equal combination of DNA from your mother and your father, your mtDNA came from the cytoplasm of your mother's ovum.

Q22. DNA allows scientists to study genetic variations among individuals of the same species, as well as the genetic variation among different species. This helps scientists to track the evolution of a species through time.

Comparing the DNA of ancient plants, animals, and even bacteria, with the DNA of their modern counterparts can reveal such varied information as the ancestry of modern organisms, the movement of populations through time, the evolution of particular disease-causing bacteria, and the way that ecosystems respond to climate change.

Student Textbook page 649

Q23. (a) Specificity: The cuts made by an endonuclease are specific and predictable. That is, the same enzyme will cut a particular strand of DNA the same way each time, producing an identical set of small DNA fragments called restriction fragments.

(b) Staggered cuts: Most restriction endonucleases produce a staggered cut that leaves a few unpaired nucleotides on a single strand at each end of the restriction fragment. These short strands, often referred to as "sticky ends," can then form base pairs with other short strands that have complementary strands, creating a recombinant DNA molecule.

Thought Lab 18.4: Recreating the First Chimera

Student Textbook page 649

Purpose

The purpose of this investigation is to develop a plan to simulate the Cohen-Boyer experiment, and demonstrate the use of restriction endonucleases and DNA ligases to create a genetically engineered organism.

Outcomes

- 30–C3.2s
- 30–C3.4s

Advance Preparation

When to Begin	What to Do
1 day before	■ Photocopy **BLM 18.3.7 (HAND) Thought Lab 18.4: Recreating the First Chimera** and **BLM 18.3.8 (HAND): Cohen-Boyer Experiment**

Materials
■ Materials are determined by students

Time Required

- 1 hour to read about the Cohen-Boyer experiment and to plan their simulation
- 1 hour to construct their simulation and answer the Analysis questions

Helpful Tips

- Use **BLM 18.3.7 (HAND) Thought Lab 18.4: Recreating the First Chimera** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 18.3.7A (ANS) Thought Lab 18.4: Recreating the First Chimera Answer Key**.
- Photocopy and distribute **BLM 18.3.8 (HAND): Cohen-Boyer Experiment**. This BLM provides additional information on the Cohen-Boyer experiment.
- Provide students with time to identify the key steps in the Cohen-Boyer experiment. This could include giving them time to conduct additional research in the library or on the Internet. Gifted students may want to identify and research other restriction enzymes as well.
- Use the Internet to provide students with an example(s) of chimeras from Greek mythology. This will allow them to make the connection between the term and visual references to these mythological entities.
- Provide students with a rubric or other tool(s) that you will be using to assess their simulated genetic engineering experiment.
- This Thought Lab can also be done in groups of 2-3 students.

Safety Precautions

- If the students plan to use edible materials to simulate the Cohen-Boyer experiment, remind them not to eat anything from the science lab.

Answers to Analysis Questions

1. Student answers are completely dependent on the simulation that they planned. Their answers should clearly demonstrate how the action of an endonuclease and ligase was illustrated in the simulation.

2. (a) Cohen and Boyer inserted an amphibian gene encoding rRNA into pSC101 (a bacterial plasmid). The plasmid contains a single site cleaved by the restriction endonuclease EcoRI; it also contains *tet*^{r}, a gene which confers resistance to the antibiotic tetracycline. The rRNA-encoding gene was inserted in pSC101 by cleaving the amphibian DNA and the plasmid by EcoRI and allowing the complementary sequences to pair. There were two phenotypes produced:

- Some of the bacterial cells immediately became resistant to tetracycline, indicating that they had incorporated the pSC101 plasmid with its antibiotic-resistant gene.
- Some of these pSC101-containing bacteria also began to produce frog ribosomal RNA. Boyer concluded that the frog rRNA gene must have been inserted into the pSC101 plasmids in those bacteria. In other words, the two ends of the pSC101 plasmid, produced by cleavage with EcoRI, had joined to the two ends of a frog DNA fragment that contained the rRNA gene, also cleaved with EcoRI.

3. (a) Student answers will depend on their background knowledge. However, they may have remembered how scientists are using genetic engineering to produce hormones such human insulin (to treat diabetes) or human growth hormone (to treat pituitary dwarfism). They may also refer to genetically modified foods, which may or may not be a benefit to society, depending on the student's personal point of view.

(b) The following are some questions that students might raise:

- What are the potential costs and dangers associated with genetic engineering?

- Many people, including influential activists and members of the scientific community, have expressed concern that genetic engineers are "playing God" by tampering with genetic material. For instance, what would happen if one fragmented the DNA of a cancer cell, and then incorporated the fragments at random into vectors that were propagated in bacterial cells? Would these cells transmit an infective form of cancer?
- Could genetically engineered products administered to plants and animals turn out to be dangerous for consumers after several generations?
- What kind of unforeseen impacts on the ecosystem might genetically "improved" crops have?
- Is it ethical to create "genetically superior" organisms, including humans?

Assessment Options

- Collect and assess students' answers to the Analysis questions.
- Use the rubric or other assessment tool(s) that you provided to your students to assess their simulated genetic engineering experiment.

Thought Lab 18.5: Reading a DNA Fingerprint

Student Textbook page 651

Purpose

The purpose of this activity is to interpret a DNA "fingerprint".

Outcomes

- 30–C3.3s

Advance Preparation

When to Begin	What to Do
1 to 2 days before	■ Photocopy **BLM 18.3.10 (HAND) Thought Lab 18.5: Reading a DNA Finger print** and **BLM 18.3.11 (HAND): DNA Fingerprinting**

Time Required

- 30 minutes

Helpful Hints

- Use **BLM 18.3.10 (HAND) Thought Lab 18.5: Reading a DNA Fingerprint** to support this activity. Remove sections as appropriate to meet the needs of the students in your class. The answers can be found on **BLM 18.3.10A (ANS) Thought Lab 18.5: Reading a DNA Fingerprint Answer Key.**
- Photocopy and distribute **BLM 18.3.11 (HAND): DNA Fingerprinting**. This BLM has a larger image of the southern blot shown on page 651 of the student textbook. It is easier to see when it has been enlarged, and this will reduce the probability of students drawing in their textbook. To save time, make an overhead transparency of the DNA blot on this BLM and do this activity as a class discussion.
- Have students use a ruler and a highlighter pen to match the child's genes to the 4 different sets of parents.
- For questions of paternity, DNA samples obtained from the mother, the child, and possible fathers are fingerprinted. A child's DNA is a composite of its parents' DNA. Therefore, comparison of DNA fragmentation patterns obtained from the mother and child will give a partial match. Bands in the child's fingerprint that are not present in the mother's must have been contributed by the father. In other words, because of allelic differences, not all of the bands present in the parents' fingerprint will appear in the child's fingerprint. However, the bands that do appear in the child's fingerprint must be found in either the father's or mother's fingerprint.
- If time and your budget allow, consider purchasing DNA Fingerprinting kits from a scientific supply company. Simple kits can be purchased from under $100. This will allow students to actually perform their own investigation. You can also make homemade gel electrophoresis kits. A number of web sites that have instructions on the materials that you can use to demonstrate this process to your students can be found at **www.albertabiology.ca**, , Online Learning Centre, Instructor Edition, Teacher Web Links.

Answers to Analysis Questions

1. The parents of the child are Parents B. They are the only parents that have all of the same DNA segments as the child.
2. Five of the child's DNA segments (50 percent) match the mother, and the other five (50 percent) match the father.
3. Other situations where DNA fingerprinting may be useful are in paternity cases, identifying the remains of murder or accident victims, tracing the movement of wildlife, or in plant and animal breeding programs.

Assessment Options

- Collect and assess the answers to the Analysis questions.
- Consider using this activity as a class discussion rather than as an assessment tool.

Section 18.3 Review Answers

Student Textbook page 651

1. A germ line mutation will likely affect all the daughter cells of that stem cell line, and is potentially more dangerous for the tissue than a mutation in a mature non-stem somatic cell. That cell will likely die as part of its natural aging process, or as a result of the mutation. Mutations that occur in spermatogonial or oogonial cells that do not affect the development of viable sperm or eggs are likely to contribute to the variations among organisms because they may be transmitted to the offspring.

2. A frameshift mutation occurs when a gene is altered by the insertion or deletion of one or two nucleotides, and it is usually more serious than a substitution mutation. The resulting shift in the reading frame usually causes a nonsense mutation, a mutation that results in a non-functional protein. On the other hand, a substitution mutation of a single nucleotide may lead to a slightly altered, but still functional polypeptide (mis-sense mutation). Mis-sense mutations can be harmful, but generally less so than frameshift mutations.

3. Older people are at a higher risk of developing cancers because they likely have accumulated more mutations in their cells. There is also a chance of more mutations because over time they have been exposed to more mutagens than a younger person.

4. DNA analysis allows scientists to study genetic variations among individuals of the same species, as well as species suspected of being closely related. This helps scientists develop an understanding of ancient ecosystems, and track the evolution of a species through time. For example, the analysis of non-coding stretches of DNA tends to show a higher mutation rate than the DNA within genes. The higher mutation rate leads to extensive genetic variations among individuals of the same species.

5. A restriction endonuclease is an enzyme that "recognizes" a short sequence of DNA nucleotides (called the target sequence) on a strand of DNA. The restriction endonuclease cuts the strand at a particular point within the nucleotide sequence, known as a restriction site. Many different endonucleases have been isolated, and each recognizes a different target sequence.

Two characteristics of restriction endonucleases that make them useful to genetic researchers are specificity and staggered cuts. Specificity refers to the cuts made by an endonuclease in the target sequence of DNA, resulting in nucleotides that are specific and predictable. That is, the same enzyme will cut a particular strand of DNA at the same location each time, producing an identical set of small DNA fragments, called restriction fragments.

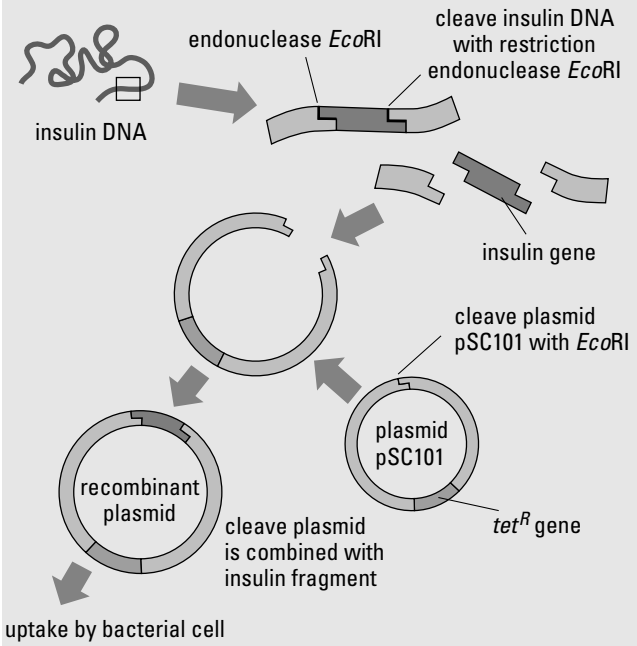
When restriction endonucleases produce a staggered cut, a few unpaired nucleotides are left on a single strand at each end of the restriction fragment. These short strands, often referred to as "sticky ends", can then form base pairs with other short strands that have a complementary sequence.

6. (a) A silent mutation results if the substitution causes coding of the same amino acid.

(b) A mis-sense mutation results when the substitution causes coding of a different amino acid, resulting in a slightly altered protein.

(c) A nonsense mutation results when the substitution causes coding of a different amino acid, and the resulting polypeptide is non-functional, such as if the mutation produces a "stop" codon prematurely before the entire polypeptide is synthesized.

7.



Students' diagrams should show how a restriction endonuclease can target a starting sequence of DNA nucleotides coding for the polypeptide for human insulin. The DNA segment of insulin can be excised and inserted into a bacterial cell. There the "sticky ends" pair with a complementary nucleotide in the bacterial cell, and are joined with DNA ligase to seal the break between them. The bacterial cell with the human insulin gene will be grown to produce insulin that can be extracted from the culture.

18.4 Genetics and Society

Student Textbook pages 652–661

Section Outcomes

Students will:

- explain how the insertion of new DNA sequences into cells can transform organisms
- describe some of the social, environmental, and ethical issues associated with genetic technologies

Key Terms

biotechnology
DNA microarray
copy DNA (cDNA)
transgenic
bioremediation
clone
ultrasound
amniocentesis
chorionic villi sampling
genetic marker
DNA probe
gene therapy
DNA vector
somatic gene therapy
germ-line therapy

Biology Background

- The *Genographic Project*, a five-year venture using DNA samples provided by volunteers from around the world as a tool to learn more about the migrations of ancient peoples, was launched in 2005 by the National Geographic Society and IBM. The project maps the presence and frequency of genetic markers in human populations to trace the migration of *Homo sapiens* around the globe over the course of human history. From their origins in Africa 60 000 years ago, humans have spread out to the farthest extremes of the planet. The study aims to use the DNA samples of over 100 000 people from as many as five continents to trace human migration. Test swabs of saliva from volunteers, including Aboriginal people and members of the general public, have been providing the DNA that is tested for markers on mitochondrial DNA and Y chromosomes. By February 2006, over 115 000 individuals had already taken part in the study.

Teaching Strategies

- This section provides a wonderful opportunity to make the connections among Science, Technology, Society, and Environmental contexts. You will likely have students that both support and reject genetic engineering and biotechnology, especially in the area of genetically modified foods. Provide students with a forum to present their points of view in a debate or class discussion.
- The following captures some of the debate concerning genetic engineering especially in humans. It could be used to help focus students' answers on some of the Chapter and Unit Review questions: Gene therapy is used for the treatment of diseases that are otherwise difficult to cure. The regulations applied to the use of this procedure should be to prevent its use. Producing children with high intelligence is a form of eugenics that was held in high regard by some people in the 20th century. Eugenics is a social philosophy that advocates the improvement of human hereditary traits by social and medical means. Some of the goals were to create healthier, more intelligent people, and reduce human disease. It was proposed that these goals could be achieved by prenatal testing and screening, genetic counseling, birth control, selective breeding, *in vitro* fertilization, and gene therapy. Opponents argue that eugenics is pseudoscience, that it could "objectify" human characteristics, and that historically it was used in coercive state-sponsored discrimination and human rights violations, and even genocide.
- Check with your local media distribution outlet to see if they have any videos that discuss genetic engineering and biotechnology.
- **BLM 18.4.4 (HAND) Cloning a Carrot** provides an additional investigation for this section in which students grow isolated carrot cells in a nutrient agar for several weeks and observe changes in cell growth.
- **BLM 18.4.1 (OH) DNA Microarray, BLM 18.4.2 (OH) Golden Rice, BLM 18.4.3 (OH) Cloning, BLM 18.4.5 (OH) Prenatal Diagnosis,** and **BLM 18.4.6 (OH) Gene Therapy** are informational BLMs that can be used to support your presentations throughout this section.

SUPPORTING DIVERSE STUDENT NEEDS

- The marginal features such as the Biology File: Web Links, and the questions posed in the captions of some of the figures in this chapter can be used to challenge students who are achieving at a high level. Many of the features require a great deal of research, which might appeal to these students while other students in your class are working through core material presented in the text.

Answers to Questions for Comprehension

Student Textbook page 653

Q24. A DNA microarray experiment allows scientists to analyze the activity of thousands of genes at once. It is generally used to compare gene expression.

Q25. The results of DNA microarray analysis allow scientists to pinpoint the genes that are responsible for particular functions or conditions, to study the interactions among genes, or to gather information about the relationship between environmental conditions and gene expression.

Q26. Studying the human genome, as a whole, offers the potential for developing drugs that are tailored not only to the expression of individual genes associated with particular disorders, but also to the unique genome of the individual. Studying the differences in gene expression among individuals can help medical researchers understand why certain drugs work better in some people than in others, and why certain people experience side effects from medications.

Biology File: Web Link

Student Textbook page 654

The following is a summary of patent laws from Canada, United States, Europe, and Japan:

- Canada: In Canada, higher life forms are not considered patentable because they do not fit the definition of "invention." Our trading partners elsewhere in the world have been allowing private industry to patent forms of life (such as types of mice and pigs) since the late 1980s. Human genes have also been patented. Patents have been available in Canada since 1982 for all types of microorganisms, including those used in the food industry for making cheeses, and for viruses and bacteria in the medical profession. Genes and DNA sequences currently fall into the category of "composition of matter" under Canadian law, which means that they fall within the definition of "invention" and can be patented.
- United States: A patent is a legal right granted by the government that gives the patent-holder the exclusive right to manufacture and profit from an invention. While naturally occurring substances in their natural form are not patentable, a very wide range of biological materials have been the subject of patents. In 1980, the U.S. Supreme Court decision in *Diamond* v. *Chakrabarty* indicated that "anything under the sun made by man" is patentable. Under certain conditions, patent protection is available for genetic information, plants, non-human animals, bacteria, and other organisms.

  For naturally occurring substances, patent protection can only be obtained if someone has changed the substance so that it is no longer the same as it is found in nature. For genes, this means that the particular gene of interest must be isolated from other genetic material, such as a chromosome.
- Europe: Inventions which are new, involve an inventive step, and are susceptible to industrial application are patentable even if they concern a product consisting of, or containing, biological material. Biological material which is isolated from its natural environment or produced by means of a technical process may also be the subject of an invention.

  The following are not patentable:
  - plant and animal varieties;
  - essentially biological processes for the production of plants or animals, such as crossing or selection. This exclusion from patentability does not, however, affect the patentability of inventions which concern a microbiological process;
  - the human body and the simple discovery of one of its elements, including the sequence or partial sequence of a gene.

  However, an element isolated from the human body or produced by means of a technical process, including the sequence or partial sequence of a gene, may constitute a patentable invention.

  The following inventions include those that are not patentable where their exploitation would be contrary to public policy or morality:
  - processes for cloning human beings;
  - processes for modifying the germ-line genetic identity of human beings;
  - uses of human embryos for industrial or commercial purposes;
  - processes for modifying the genetic identity of animals which are likely to cause them suffering without any substantial medical benefit to man or animal, and also animals resulting from such processes. [Source: http://europa.eu.int/scadplus/leg/en/lvb/l26026.htm]
- Japan: Genetic resources are a fundamental component of biotechnology research and the commercialization of it. In order to ensure the sound development of biotechnology and bioindustry, it is essential to create an environment that facilitates access to genetic resources.

  Biogenetic resources including animals, plants, microorganisms, human cells/tissues and genes are extremely useful, yet at the same time limited, in industrial applications and research. Enhancing these resources is truly important from the viewpoint of international competition. All relevant parties must join forces in gathering, securing and providing biogenetic resources, including genetic information, so as to strengthen the foundation of industrial competition, and help Japan to protect its rights in this area.

  In the spirit of the Biodiversity Convention, Japan must achieve coordination and cooperation with countries in the gathering, securing, and provision of such resources. [Source: http//www.wipo.int/tk/en/genetic/proposals/japan.pdf]

Student Textbook page 655

Students will find a wide range of concerns listed on numerous web sites. These concerns include harm to human health, environmental damage, the release of new viruses, gene transfer to indigenous species, and as yet unknown damage.

Different regulatory mechanisms, such as risk assessment or testing programs, are carried out by the governing organizations in different countries.

Answers to Questions for Comprehension

Student Textbook page 658

Q27. The benefits of transgenic organisms include improving human health, cleaning up toxic spills, producing plants with more nutritional value, producing pharmaceutical products, and producing animals that could serve as organ donors for humans.

Examples include (students are only asked to provide one example of each):

- Transgenic bacteria are making pure human insulin, making medicines at lower costs, and are used to clean up oil spills.
- Transgenic plants, such as golden rice, provide higher nutritional value to feed those who are starving.
- Transgenic animals, such as goats, are genetically modified to secrete a human polypeptide or other substances in their milk.

Q28. Social, legal, and moral issues associated with transgenic organisms involve environmental threats, health effects, and social and economic issues. These concerns are summarized below:

- Environmental threats: The use of herbicide-resistant plants could encourage farmers to use higher levels of herbicides. This, in turn, could lead to a build up of herbicide chemicals in water supplies and neighbouring ecosystems. As well, there is evidence that engineered genes can be transferred to wild plants and other organisms, raising concerns about the emergence of "superweeds" and "superbugs." More generally, ecosystems involve complex and delicate balances among many different organisms. The introduction of transgenic bacteria, plants, or animals could upset these balances, with unknown results.
- Health effects: Many consumer groups argue that not enough is known about the long-term effects of consuming transgenic products, including genetically modified foods and medicines. The complex processes of gene regulation are not well understood, so it is difficult to predict potential health risks.
- Social and economic issues: Advocates of genetically modified foods argue that these foods will help to improve human health and alleviate world hunger. Their opponents argue that genetic research absorbs millions of dollars, which would be better spent directly helping people in need. In addition, many people are concerned about the growing influence of private corporations over global food production. The treatment of plants and animals as commodities to be manipulated and patented also raises questions about our relationships with—and responsibilities to—other living organisms.

Student Textbook page 660

Q29. (a) During an ultrasound procedure, sound waves beyond the limit of human hearing are sent through the amniotic fluid. The sound waves bounce off the developing fetus and are used to create a cross-sectional image of the fetus. This image can reveal physical abnormalities, such as a missing limb, malformed heart, or cleft palate. Many other genetic conditions, however, can be identified only by analyzing a tissue sample from the fetus.

(b) In an amniocentesis, a needle is used to withdraw a small sample of amniotic fluid from the uterus. The extracted fluid is placed in a special nutrient-rich medium and the cells are allowed to multiply. When the cell sample is large enough, researchers can prepare a karyotype or another genetic analysis. The karyotype can be used to identify chromosomal disorders, such as Down's syndrome.

(c) A DNA marker can be found using a DNA probe. A DNA probe consists of a molecule of DNA with a nucleic acid sequence that is complementary to the marker sequence, and is "marked" with a radioactive or fluorescent chemical tag. DNA from the tissue sample is placed in a suspension with the DNA probe. If the DNA sample contains the gene of interest, the probe will bind to the marker sequence. Using the tag, researchers can verify the presence of the gene of interest.

Section 18.4 Review Answers

Student Textbook page 661

1. Studying the human genome offers the potential for developing drugs that are tailored not only to the expression of individual genes associated with particular disorders, but also to the unique genome of a patient. Studying the differences in gene expression among individuals can also help medical researchers understand why certain drugs work better in some people than in others, and why certain people experience side effects from medications.

2. A DNA microarray is a chip (usually a glass microscope slide or a polymer membrane) that contains a grid of thousands of cells. Each cell contains a nucleic acid sequence that can bind with one of the mRNA molecules transcribed during gene expression.

A DNA microarray allows scientists to analyze the activity of thousands of genes at once. The results of a microarray allow scientists to pinpoint the genes that are responsible for particular functions or conditions, to study the interactions among genes, or to gather information about the relationship between environmental conditions and gene expression.

3. **(a)** Some of the issues that might be considered are: Who owns the genetic information? Should companies have the right to sell DNA information to other companies without the permission of the people who provided the samples? Should companies that use DNA in medical research be required to share the results of their work with the individuals, or communities, whose genetic information was used? Where is the boundary between public and private genetic property rights?

   (b) Providing genetic information should be voluntary. Genetic information can provide medical benefits to many. Research should be funded so as to maximize benefit, for as many as possible. It is reasonable for companies to expect a return on their investment in genetic research. The outcome of the research should be widely available.

4. **(a)** Prior to approving the plant for use and human and livestock consumption, it should be demonstrated that it is safe and there are no short-term, nor long-term adverse effects resulting from its consumption. Testing on laboratory animals may not be conclusive in determining whether of not it is safe for human consumption. The benefits are that this transgenic carrot plant can be grown without the use of harmful pesticides.

   (b) The advantages include that this plant can be grown without the use of harmful pesticides that may affect other organisms. The development of this plant was expensive, and this cost is passed on to the farmer. Genetically modified and organically grown foods are generally more expensive than non-modified crops that are treated with pesticides.

   (c) Responses will reflect the student's beliefs on this issue. An example answer might be: Yes, consumers should be aware of what they are buying. Informed choices can only be made if the consumer is provided with the information upon which to base his/her decision. Arguments that could be made to support the other viewpoint include:

   - If Health Canada and other similar agencies have policies to protect the public, then it should not be necessary to provide detailed information, other than labelling the product as being tested and approved for consumption by a reputable agency.
   - Informing the public of the details of testing and approving consumer products could be costly, and may be difficult for the public to understand.

5. **(a)** During an ultrasound procedure, sound waves beyond the limit of human hearing are sent through the amniotic fluid. The sound waves bounce off the developing fetus and produce a cross-sectional image of the fetus. This image can reveal physical abnormalities, such as a missing limb, malformed heart, or cleft palate.

   (b) In chorionic villi sampling, cells from the chorion can be removed and examined to determine their genetic information. This may reveal whether or not the fetus is at risk of developing a genetic abnormality.

6. A DNA probe consists of a molecule of DNA with a nucleic acid sequence that is complementary to a specific genetic marker sequence, "marked" with a radioactive or fluorescent chemical tag. DNA from the tissue sample is placed in a suspension with the DNA probe. If the DNA sample contains the gene of interest, the probe will bind to the marker sequence. Using the tag, researchers can verify the gene of interest and possible genetic abnormality, as genetic makers for many human genetic disorders have been identified.

7. Somatic gene therapy is aimed at correcting genetic disorders in somatic cells (cells that do not produce eggs or sperm). This therapy can improve the health of a patient; it does not prevent the disorder from being passed on to the patient's children. Germ-line therapy is used to modify the genetic information carried in egg and sperm cells. In theory, this kind of therapy could eliminate inherited genetic disorders. In reality, however, it could have many unforeseen effects on future generations. Human germ-line therapy research is currently banned in Canada and in many other countries.

   Somatic gene therapy can be used in the treatment of cancer by inserting a gene that destroys cancer cells into somatic cells that are at risk of becoming a malignant cancer. Thus, the precancerous cells may be destroyed before cancer can develop. Similarly, by using germ-line therapy and inserting a gene that destroys cancer cells into germinal oogonial or spermatogonial cells whose family history show a risk of cancer, any precancerous cells may be destroyed before cancer can develop.

Connections Feature (Social and Environmenta Contexts)

Biotechnology: Assessing Unintended Consequences

Student Textbook page 662

Teaching Strategies

- Photocopy and distribute Assessment Checklist 7 Independent Research Skills, found in Appendix A of the Teacher Resource. Students can use this handout to guide their research.
- Web links related to this topic can be found at **www.albertabiology.ca**, Online Learning Centre, Student Edition or Instructor Edition, Web Links.

Answers to Questions

1. Student responses will reflect their beliefs regarding this issue. A possible answer is: Government regulations do

require testing of new products, technology, and procedures before they are approved for use by the general public. For example, Health Canada and The Federal Drug Administration in the United States regulate the use of new drugs. While this may be an effective way to protect the general public from risks associated with biotechnology, in some instances, personal risk assessment may be a better option. A person who is terminally ill may wish to have a "last resort" treatment, or access to a drug that has not been approved for use by these government agencies. Thus, in some specific cases, government regulations may not serve the individual.

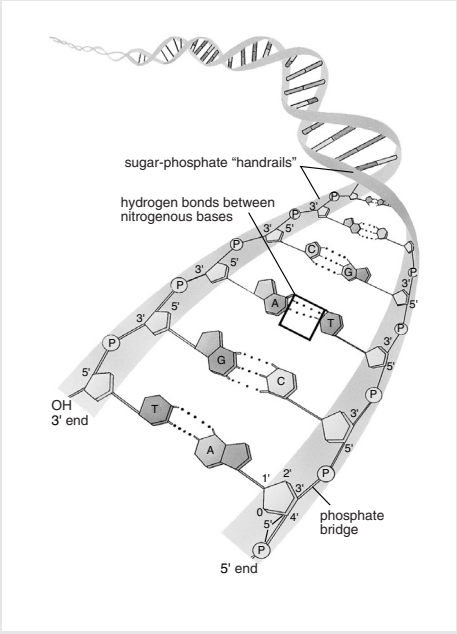
2. Student responses will reflect their beliefs regarding this issue. A possible answer is: No, the risks and benefits of a new technology are varied because not everyone may wish to use the new technology, or their response to it may vary because of individual differences. Yes, I believe that new technologies should benefit everybody in society equally. It is desirable to have medical genetic technologies benefit as large a segment of the population as possible.

Chapter 18 Review Questions

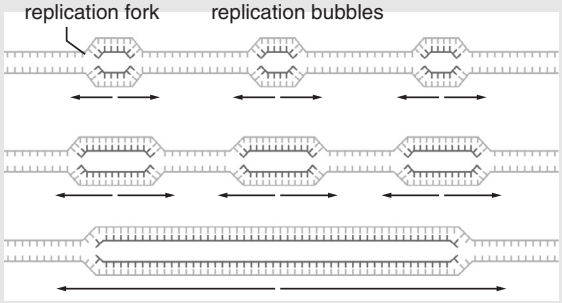
Student Textbook pages 664–665

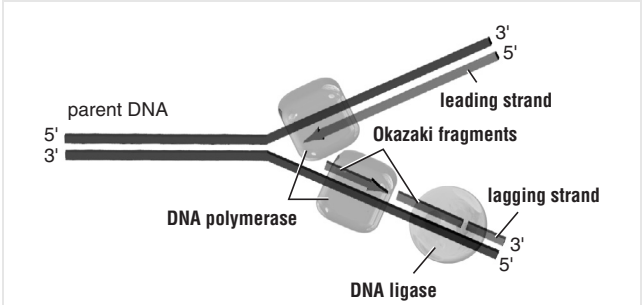
Answers to Understanding Concepts Questions

1. Alfred Hershey and Martha Chase used radioactive labelling to determine whether viral protein or viral DNA was responsible for taking over the genetic machinery of the host cell. Hershey and Chase produced two batches of the virus. In one batch, they labelled the protein coat using radioactive sulpfur. In the other batch, they labelled the DNA with radioactive phosphorus. The labelled viruses were allowed to infect bacterial cells. The cells were then agitated in a blender to separate the viral coats from the bacterial cells. Each medium was tested for radioactivity. The results demonstrated that viral DNA, not viral protein, enters the bacterial cell, and that DNA is the hereditary molecule.
2. Chargaff's rule states that in the DNA nucleotides, the amount of adenine will be more or less equal to the amount of thymine, and the amount of guanine will be equal to the amount of cytosine. The number of A-T nucleotides will not necessarily equal the number of C-G nucleotides. This overturned Levene's earlier hypothesis that the nucleotides occurred in equal amounts and were present in a constant and repeated sequence, such as ACTGACTGACTGACTG.
3. Students' illustrations may resemble Figure 18.6 (shown below) in the student textbook, and should include appropriate labels, as given in that figure.



4. The DNA strand that is complementary to the sequence TTCGAATCGA is AAGCTTAGCT.
5. Students' illustrations may resemble Figure 18.9 and 18.10 (shown below) in the student textbook, and should include appropriate labels, as given in those figures.





6. Helicases cleave DNA. Primase synthesizes a new RNA strand. DNA polymerase adds nucleotides to a fragment of DNA. Ligase binds nucleotides together.
7. After each nucleotide is added to a new DNA strand, DNA polymerase recognizes whether or not hydrogen

bonding is taking place between the new nitrogen base and its complement on the original strand. The absence of hydrogen bonding indicates a mismatch between the bases.

8. The genetic code has three important characteristics.

- The genetic code is *redundant*—that is, more than one codon can code for the same amino acid. Only three codons do not code for any amino acid. These codons serve as "stop" signals to end protein synthesis. If a mistake occurs when the genetic code is replicated or transcribed, redundancy reduces the chance that a different amino acid results during translation.
- The genetic code is *continuous*. That is, the genetic code reads as a series of three-letter codons without spaces, punctuation, or overlap. Where to start and stop translation is essential. A shift of one or two nucleotides will alter the codon groupings and result in an incorrect amino acid sequence.
- The genetic code is nearly *universal*. Almost all organisms have the same genetic code. This has important implications for gene technology, since a gene that is taken from one species and inserted into another species will produce the same protein.

9. (a) A codon is a specific sequence of three mRNA nucleotides, the nitrogen bases of which code for an amino acid. The mRNA "reads" the genetic information of the DNA, and transfers that information to ribosomes in the cytoplasm, where a corresponding polypeptide is synthesized.

(b) An anticodon is a specific sequence of three tRNA nucleotides, the nitrogen bases of which complement those on the mRNA. The tRNA carries a specific amino acid to the ribosome and attaches the amino acid to the growing polypeptide chain according to the complementary mRNA codon.

(c) The ribosome is the site of protein synthesis, and moves along the mRNA chain as each codon is read by a tRNA that carries a specific amino acid to the polypeptide chain.

10.

Type of RNA	Functions of RNA in gene expression in eukaryotic cells
mRNA	Messenger RNA "reads" the genetic information on the DNA. mRNA is processed before it moves to the cytoplasm for translation.
rRNA	Ribosomal RNA is in the ribosomes that move along an mRNA chain as each codon of mRNA is "read" by a tRNA anticodon.
tRNA	Transfer RNA picks up and carries a specific amino acid to the mRNA chain on the ribosome, according to the complementary triplet codon/anticodon of nitrogen bases.

11. A physical mutagen damages DNA by changing its physical structure; for example, X-rays may cause the loss of large portions of chromosomes and ultraviolet radiation may cause distortions in the DNA molecule, which can interfere with replication. A chemical mutagen damages DNA by reacting chemically with the DNA molecule; for example, cancer-causing chemicals cause changes to nucleotide sequences and these incorrect sequences are incorporated into replicated DNA.

12. A restriction endonuclease is an enzyme that "recognizes" a short sequence of DNA nucleotides (called the target sequence) on a strand of DNA. The restriction endonuclease cuts the strand at a particular point within the nucleotide sequence, known as a restriction site. Two characteristics of restriction endonucleases that make them useful to genetic researchers are specificity and staggered cuts. Specificity refers to the cuts made by an endonuclease in the target sequence of DNA, and the resulting nucleotides are specific and predictable. Most restriction endonucleases produce a staggered cut that leaves a few unpaired nucleotides on a single strand at each end of the restriction fragment. These short strands, often referred to as "sticky ends," can then form base pairs with other short strands that have a complementary sequence.

13. No, endonucleases would cut DNA segments, but without the DNA ligase enzyme, the sticky ends of the DNA would not be spliced together to form a stable recombinant DNA molecule.

14. (a) One sheep was the egg cell donor, from which the nuclei of several egg cells were removed and discarded. Another sheep was an udder cell donor, from which the nuclei from several cells were removed and transplanted into the enucleated egg cells. These new egg cells with the udder cell nuclei were electrically stimulated to undergo cell division, and then the resulting embryonic mass of cells was inserted into the uterus of a surrogate mother sheep.

(b) Dolly's clone was the sheep who donated the udder cell nuclei since these nuclei contain the genetic information.

15. (a) An ultrasound image may show physical abnormalities of the fetus.

(b) A fetoscopy uses a miniature camera inserted into the uterus to show more external detail of the fetus than an ultrasound image.

(c) Chorionic villi sampling removes a sample of fluid and cells from the chorionic villi (part of the fetal placenta, which can be tested for various genetic disorders). A karyotype of the chromosomes is prepared to determine larger chromosomal abnormalities.

(d) Amniocentesis removes a sample of amniotic fluid and fetal cells that are cultured and tested for various genetic disorders. A karyotype of the chromosomes is

prepared to determine larger chromosomal abnormalities.

Answers to Applying Concepts Questions

16. It is likely that the virus has RNA, because uracil that is found in RNA is present, and thymine that is found in DNA is absent.

17. (a) Translation is occurring as the ribosomes are reading the mRNA, and the tRNAs are assembling amino acids to the growing polypeptide chain.

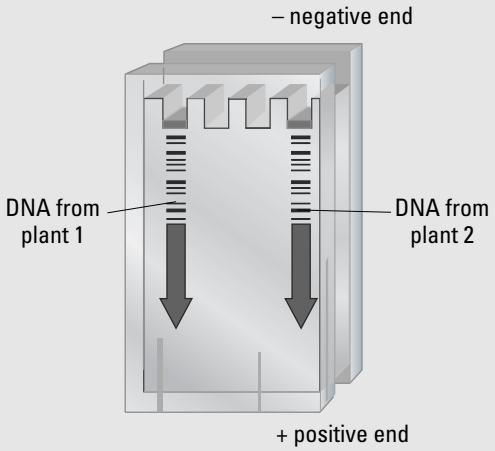
(b) These processes are occurring in a prokaryotic cell because ribosomes and DNA are not found together in the cytoplasm of eukaryotic cells. Instead, DNA remains in the nucleus.

18. (a) If the gene for stoat coat colour could be isolated with endonuclease, the DNA could be inserted into a dog egg cell, which could then be artificially fertilized and implanted into the uterus of a dog. If the coat colour gene was coded for, the offspring may show stoat coat colour.

(b) Consideration should be given to the biological characteristics of the transgenic product, compared with the characteristics of the natural variety. Will the dog be healthy and able to breed? Will the dog have adverse behavioural characteristics and how will these be controlled?

19. (a) Restriction enzymes are added to a sample of DNA from each plant. The enzymes cut the DNA into fragments. Small amounts of the DNA sample are placed into gel electrophoresis wells. An electric charge is attached to the gel, and the DNA segments migrate in the gel according to their lengths. The resulting DNA "fingerprints" are analyzed to determine if segments from the two plants match, indicating whether the plants would be clones (genetically identical).

(b) A diagram similar to that shown below would indicate identical DNA segments for each of the two plants.



20. A DNA probe with a nucleic acid sequence CCGTAATAGGC that is complementary to the gene sequence GGCATTATCCG, which is associated with stunted growth, is "marked" with a radioactive or fluorescent chemical tag. DNA from the tissue sample is placed in a suspension with the DNA probe. If the DNA sample contains the gene for stunted growth in mice, the probe will bind to the marker sequence, indicating the presence of the gene.

Answers to Making Connections Questions

21. (a) There is no set relationship between the complexity of an organism (number of genes in an organism) and the total size of its genome. An organism may have an enormous number of base pairs in its genome and very few genes if the bulk of its genome consists of non-coding "junk" DNA.

(b) Comparing the genomes of the two organisms would show what genes they have in common, and would indicate their evolutionary relationship—how closely or distantly related they are.

22. The different tissues all develop from the same fertilized egg cell (zygote). While the tissues have the same genes, only those genes necessary for a specific tissue's functions are active.

23. There are some similarities; however, DNA "words" are limited to sequences of amino acids. Each section of code has only "one meaning"—resulting in one specific protein. This does not compare to the arrangement of letters in a language, which results in words that can have a great variety of meanings.

24. Students' answers will depend on their point of view. In support of human cloning, a response might be that cloning can contribute to further understanding of the complexities of gene expression in humans. Against human cloning, a response might be that cloned offspring have a high mortality rate, and also have a high incidence of disease. Many clones show signs of metabolic disorders, such as premature aging.

25. Studying viral genetics could lead to an understanding and treatment of viral diseases in humans that would benefit all society. There may be a greater benefit to society from knowing how to treat viral diseases than from understanding human genetics. The moral and ethical issues that are associated with the study of human genetics are not an issue when studying viral genomes.

26. Eating preserved foods containing nitrites should be done in moderation to limit the exposure to these mutagens. The amount of nitrite preservative added to processed foods is regulated to minimize the exposure from eating any one food product. The risk of exposure to nitrites may be less than that resulting from bacterial toxins in foods that spoil because the nitrite preservatives are absent.

27. (a) The potential advantages of this transgenic fish are that more salmon are produced in a shorter time and a high protein food is produced more quickly.

(b) The potential risks associated with this fish are: The transgenic salmon require more nutrients in a short growth cycle. Transgenic salmon that are grown in crowded conditions have a greater risk of contracting and spreading disease to other fish—both the transgenic and the wild stocks. Transgenic salmon that escape from the holding pens may breed with wild salmon and adversely affect wild salmon stocks.

(c) Commercial fish-farming operations should have measures in place that prevent diseases from being transmitted to other fish. Commercially grown fish should be contained to prevent escape and breeding with wild fish.

28. Ethical dilemmas that arise from our ability to detect genetic disorders before birth include: terminating pregnancy (therapeutic abortion) to prevent the birth of a child with a serious genetic disorder; the risks to the child and mother of treating a fetus in the uterus; determining who should bear the financial burden of expensive treatments; and does society have a responsibility to inform and counsel parents who are at risk of producing a child with a genetic disorder in future pregnancies?

Ethical dilemmas that arise from our ability to detect genetic disorders after birth include: the possible emotional and financial burdens to family and society of raising a child with a genetic disorder; and does society have an obligation to inform parents of the probability of producing a child with the same genetic disorder? If there is a high probability of a genetic disorder in a future child, what responsibility do society, the immediate family, and the parents have in deciding whether a future pregnancy should occur?

Career Focus: Ask a Cancer Geneticist

Student Textbook pages 666–667

Teaching Strategies

- Have students research the education and training requirements for a cancer geneticist.
- Have students research one or more of the different types of cancer mentioned in the Career Focus, and then do a short presentation of their findings to the rest of the class.
- Be sensitive to the fact that it is highly likely that one or more of your students will have first hand experience dealing with a cancer patient. This discussion could be very emotional for these individuals.

Answers to Go Further... Questions

1. Proto-oncogenes are transformed into oncogenes through:

- Mutation: A tiny change in a proto-oncogene can convert it into an oncogene. The mutation results in an oncogene that produces a protein with an abnormal structure. These mutations often make the protein resistant to regulation and cause uncontrolled and continuous activity of the protein.
- Chromosomal Translocation: Chromosomal translocations, which can result from errors in mitosis, have also been implicated in the transformation of proto-oncogenes into oncogenes. Chromosomal translocations result in the transfer of a proto-oncogene from its normal location on a chromosome to a different location on another chromosome.
- Gene Amplification: Some oncogenes result when multiple copies of a proto-oncogene are created (gene amplification). Gene amplification often results in hundreds of copies of a gene, which results in increased production of proteins and increased cell growth. Multiple copies of proto-oncogenes are found in many tumours.

2. Normal cells have a predetermined life span and different genes regulate their growth and death. Cells that have been damaged or have an abnormal cell cycle may develop into cancer cells. Usually these cells are destroyed through a process called programmed cell death (apoptosis). Cells that have developed into cancer cells, however, do not undergo apoptosis. Mutated proto-oncogenes may inhibit the death of abnormal cells, which can lead to the formation and spread of cancer.

3. Students will likely predict that certain viruses cause the proto-oncogenes to change (mutate) into oncogenes. Cancer causing viruses are likely retroviruses, whose RNA genome is reverse transcribed into DNA of the host-cell genome. These viruses are termed oncogenic transforming viruses.

Unit 7: Review Answers

Student Textbook pages 668–671

Answers to Understanding Concepts Questions

1. The term "cell cycle" refers to the phases in the life of a somatic cell. The phases are G1, S, G2, mitosis, and cytokinesis. The first phase is G1 (Gap 1 or Growth 1) phase. In this phase, the new cell carries out rapid growth and metabolic activity. The second phase is S, or synthesis, phase. In this phase, the cell begins preparing for cell division by synthesizing a complete duplicate set of genetic material: the DNA in the nucleus is replicated. In the third phase, G2 (Gap 2 or Growth 2) phase, proteins and other molecules that are needed for cell division are produced. Mitosis is the phase of nuclear division in which the chromatin that were duplicated in S phase migrate as chromosomes to opposite poles of the cell. Finally, the cytoplasmic division of the parent cell is called cytokinesis. Here the cytoplasm and the organelles are divided between the two new daughter cells.

2. The order of events in mitosis is as follows: prophase, metaphase, anaphase, and telophase.

3. (a) A leaf cell immediately following cytokinesis will have $2n = 54$ chromosomes.

(b) A gametophyte cell at the conclusion of the S phase of mitosis will have $n = 27$ chromosomes, each of which has two identical chromatids.

(c) A sporophyte cell at the conclusion of anaphase I has the equivalent of 108 chromosomes. The 54 chromosomes—as duplicate chromatids—have separated (54 + 54) and are still in the same cell.

4. The law of segregation is derived from the separation of the chromosomes during anaphase I of meiosis. The two alleles for each characteristic segregate during the production of gametes. The law of independent assortment is derived from the assortment of the chromosomes during metaphase I of meiosis. Chromosomes are arranged independently of each other such that one allele faces one pole of the cell, and the other allele faces the other pole. Which allele faces which pole of the cell occurs by chance, and is independent of the other alleles on the other chromosomes.

5. (a) Genotype refers to the genetic make up of an individual, usually expressed as letters, for example, *PP*, *Pp*, and *pp*. Phenotype refers to the observed appearance of an individual, for example, purple flowers and white flowers.

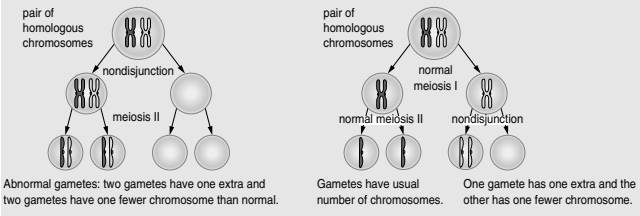
(b) In a homozygote, both alleles are the same, for example, *PP* and *pp*. In a heterozygote, the alleles are different, for example, *Pp*.

(c) When dominant and recessive alleles are present in a heterozygote, the dominant allele is fully expressed in the organism's phenotype, and the recessive allele has no noticeable effect on the phenotype.

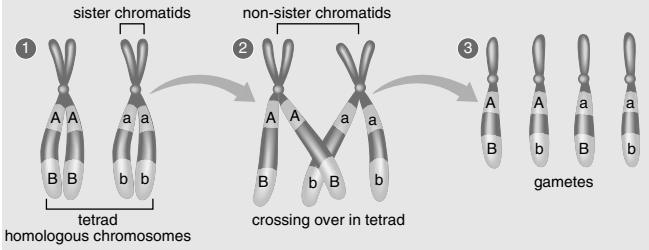
6. The probability would be in 1 in 8 388 608 (2^{23}). Of her 23 maternal and 23 paternal chromosomes, all the chromosomes from one parent would have to be facing the same pole, and all the chromosomes from the other parent would have to face the opposite pole of the cell, in metaphase I.

7. (a) Students' diagrams should resemble those below.

Nondisjunction from Figure 16.13



Crossing over from Figure 16.14A



(b) Nondisjunction is likely to result in non-viable daughter cells because the addition or deletion of chromosomes is a greater genetic change, and is likely to have more adverse consequences than crossing over.

8. In humans, all somatic cells throughout life are diploid cells with two sets of chromosomes. Testes and ovaries produce haploid sperm cells and egg cells by meiosis. Meiosis occurs prior to fertilization. Fertilization occurs internally in the Fallopian tubes of the female, and development of the offspring occurs in the uterus.

In ferns the adult multicellular sporophyte is diploid. Spores are produced by meiosis on the underside of the fronds (leaves). Spores are released, and if they land in a favourable environment, they will grow into a small haploid gametophyte. The gametophyte grows by mitosis, and produces haploid gametes that fuse. The resulting zygote grows by mitosis into a diploid adult sporophyte. The fern life cycle is an alternation of sporophyte and gametophyte generations. In humans, the haploid generation is only one cell, the sperm cell or egg cell. Reproductive advantages of the fern life cycle: Spores are small and light and can, therefore, be transported to a new environment that may be more favourable to growth and in which competition from the parent plant is reduced; gametophytes can form gametes that fuse and create a new sporophyte without fertilization, so that another fern is not required at this stage in the fern life cycle.

Reproductive advantages of the human life cycle: In the fern life cycle, the gametophyte is exposed to the environment, where it is very vulnerable due to its small size. In human reproduction, the egg and sperm (gametophytes) fuse in the Fallopian tube: the haploid cells are not exposed to the external environment.

9. (a) In terms of classical Mendelian genetics, the laws of heredity can be explained in the following ways:

- The law of segregation states that heritable factors (genes) separate during the formation of gametes in such a way that each gamete receives one copy of every factor.
- The law of independent assortment states that pairs of alleles separate independently of the alleles for

other genes during the formation of gametes. This means that traits are transmitted to offspring independently of one another.

(b) In terms of molecular genetics, the laws of heredity can be explained in the following ways:

- The law of segregation is derived from the separation of the chromosomes during anaphase I of meiosis. The two alleles of each gene segregate during the production of gametes.
- The law of independent assortment is derived from the assortment of the chromosomes during metaphase I of meiosis. Chromosomes are arranged independently of each other, such that one allele faces one pole of the cell, and the other allele faces the other pole. The two alleles for each gene assort into gametes independently.

10. (a) The F_1 generation would all be normal-winged.

(b) The F_2 generation would be 3 normal-winged:1 short-winged.

11. Cross the black-eyed fly with a grey-eyed fly. If any grey-eyed flies occur in the offspring, then the black-eyed fly is heterozygous *(Bb)*. If no grey-eyed flies occur in the offspring, then the black-eyed fly is homozygous *(BB)*.

12. The P_1 genotypes are *Ww* and *ww*.

13. (a) Normal wings = 750 offspring.

(b) Black eyes and short wings = 188 offspring.

(c) Grey eyes and short wings = 63 offspring.

14. The probability that their next child will have hemophilia (*hh*) is 0.25, or 1 in 4, as shown in the Punnett square. Students should assume that neither parent has hemophilia.

♂ \ ♀	X^H	X^h
X^H	X^HX^H	X^HX^h
Y	X^HY	X^hY

15. (a) "A" represents the transcription of DNA to mRNA.

(b) "B" represents the translation of the mRNA genetic code to a protein.

16. (a) 5'-AAATACACATGCATCTTT-3'
3'-TTTATGTGTACGTAGAAA-5`

(b) The 3' end of the segment has the free –OH group.

(c) The amino acid sequence of the polypeptide product of this gene is "methionine-cysteine-threonine-stop."

(d) Sample answer: A nucleotide substitution in the DNA segment 5'-TACACATGCATC-3' to 5'-TACACATGGATC-3' would be a point silent mutation because there is no change in the amino acid threonine, coded by TGG.

17. (a) During DNA replication, DNA polymerase inserts into the replication bubble and adds nucleotides, one at a time, to create a strand of DNA that is complementary to the parent strand.

(b) DNA ligase joins (splices) together Okazaki fragments, short fragments of DNA that are formed during the replication of the lagging strand of the parent DNA.

(c) RNA primase makes an RNA primer strand of about 10 nucleotides, to which DNA polymerase adds nucleotides during replication of the parent strand of DNA.

(d) RNA polymerase is a complex of enzymes that, during transcription, unwinds the DNA double helix. It then binds to the sense strand of the DNA molecule and synthesizes an mRNA molecule that is complementary to the sense strand of DNA.

(e) Helicase cleaves and unwinds short sections of DNA ahead of the replication fork.

18. Three types of RNA and their roles in gene expression are as follows:

- Ribosomal RNA (rRNA) is found in the ribosomes, which is where the messenger RNA (mRNA) is read and the amino acids are assembled to form a polypeptide.
- Messenger RNA (mRNA) transcribes the genes, the sequence of nitrogen bases in a strand of DNA, and carries this "message" from the DNA in the nucleus to the ribosomes in the cytoplasm.
- Transfer RNAs (tRNA) in the cytoplasm bond to individual amino acids and take them to the complementary codons of the mRNA at the binding site on the ribosome, where a growing polypeptide chain is built.

19. (a) A restriction endonuclease is an enzyme that "recognizes" a short sequence of DNA nucleotides (called the target sequence) on a strand of DNA. The restriction endonuclease cuts the strand at a particular point within the nucleotide sequence, known as a restriction site. Two characteristics of restriction endonucleases that are useful to genetic engineers are specificity and staggered cuts. These characteristics enable genetic engineers to use restriction endonucleases to create recombinant DNA.

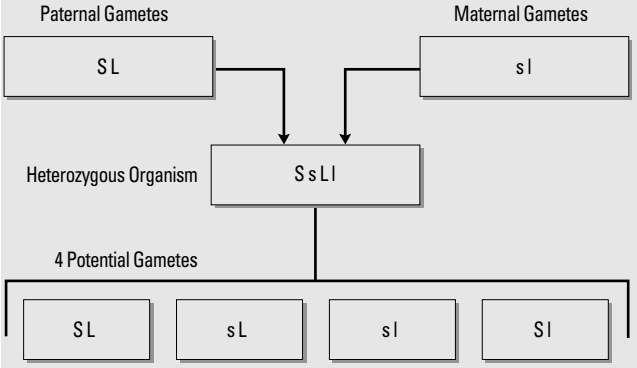
(b) A DNA microarray is a glass microscope slide or a polymer membrane that contains a grid of thousands of wells. Each contains a nucleic acid sequence that can bind with one of the mRNA molecules transcribed during gene expression. A DNA microarray allows scientists to analyze the activity of thousands of genes at once, and pinpoint the genes

that are responsible for particular functions or conditions.

(c) A DNA vector carries foreign DNA into target cells in the patient. One type of DNA vector commonly used in gene therapy trials is a modified form of virus. Viruses are well-suited to gene therapy because most have the ability to target certain types of living cells and to insert their DNA into the genomes of these cells. DNA vectors enable genetic engineers to change the function of a gene in order to treat a genetic disorder.

(d) Recombinant DNA is DNA that includes genetic material from different sources, and is used to produce certain characteristics in different organisms. For example, the gene for human insulin is inserted into bacterial DNA to manufacture insulin.

20. Note: This question should also state that the gene for long stems (L) is dominant to the gene for short stems (l).



21. If a somatic cell that has a mutation is part of the asexually reproducing tissue, then the mutation will be transmitted to the new offspring. This asexually reproducing tissue is in effect the germ line.

22. Two characteristics of restriction endonucleases that are useful to genetic researchers are specificity and staggered cuts. Specificity refers to the cuts made by an endonuclease in the target sequence of DNA nucleotides, which are specific and predictable. Staggered cuts refers to how most restriction endonucleases produce a staggered cut that leaves a few unpaired nucleotides on a single strand at each end of the restriction fragment. These shortstrands, often referred to as "sticky ends," can then form base pairs with other short strands that have a complementary sequence.

23. In gel electrophoresis, the negatively charged DNA fragments are attracted to and travel toward the positive terminal. The smaller fragments move more easily through the spaces between the protein molecules of the gel and migrate the farthest from the well.

Answers to Applying Concepts Questions

24. "Every cell is haploid for at least part of its life cycle" is not a true statement. In cell reproduction in diploid organisms, the $2n$ number of chromosomes is replicated in S phase of the cell cycle. Now the cell has the equivalent DNA of a $4n$ cell. This remains until telophase, when the chromatids, distribute now separate, into two daughter cells, "restoring" the $2n$ number of chromosomes.

25. A karyotype permits examination of the chromosomes to determine if nondisjunction has occurred and additional chromosomes are present, or chromosomes are missing. It also permits examination of the chromosomes to determine if chromosomes are missing, or have additional segments. A slide of a cell culture that is actively going through mitosis is prepared and stained. If any cells are in metaphase, the slide is photographed. Individual chromosomes are cut out of the photograph and matched according to their length and banding pattern. The arranged chromosomes are then photographed, with the resulting picture depicting the cell's karyotype.

26. The researcher is correct. Microtubules are necessary for the development of the spindle fibres, without which metaphase and anaphase cannot occur. The tumour will not reproduce, as mitosis will be arrested at prophase.

27. During S phase of the cell cycle, the replication of DNA will be disrupted. Without DNA ligase, the Okazaki fragments of DNA on the lagging strand will not be joined to form a continuous strand of new DNA. Without DNA replication, two new daughter cells, if formed, will not have a complete set of genetic material, and the cells will likely die.

28. FMF exhibits an autosomal dominant inheritance pattern.

Genotypes: I 1, I 2, II 1, II 2, III 2, III 3, III 4, and IV 1 are heterozygous (*Aa*). II 3, III 1, and IV 2 are homozygous recessive (*aa*). One cannot be sure of the genotypes of II 4 and IV 3.

Phenotypes: Individuals II 3, III 1, and IV 2 have FMF. All other individuals have normal phenotypes with respect to FMF.

29. Genotypes: II 4 and III 2 are X^LX^L. I 1, II 2, and III 3 are X^LX^l. I 2, II 1, and II 3 are X^LY. III 1 is X^lY.

Phenotypes: III 1 has Lesch-Nyhan syndrome. I 1, I 2, II 1, II 2, II 3, II 4, III 2, and III 3 have normal phenotypes with respect to Lesch-Nyhan syndrome.

30. (a) Congenital deafness is an autosomal recessive disorder. Both parents are heterozygous (*Hh*) for congenital deafness, and the recessive allele from both parents was passed to the II-3 offspring (*hh*).

(b) If the male parent is homozygous (*HH*) for normal hearing, and the female parent has congenital deafness (*hh*), then all the offspring will be (*Hh*) and have normal hearing. It is not possible to be certain of the male parent's genotype, because if he were

heterozygous (*Hh*), the probability of having a child with congenital deafness (*hh*) is 0.5.

(c) The II-3 woman is a carrier for congenital deafness (*Hh*), and her husband, who has a sister with the condition, may be either (*HH*) or (*Hh*). The Punnett square (A) shows the possible genotypes of the offspring if he is homozygous for normal hearing. The Punnett square (B) shows the possible genotypes of the offspring if he is heterozygous for normal hearing

A

	H	*H*
H	*HH*	*HH*
h	*Hh*	*Hh*

If the husband is homozygous for the dominant allele, they have no chance of having a congenitally deaf child.

B

	H	*h*
H	*HH*	*Hh*
h	*Hh*	*hh*

If the husband is heterozygous, the couple has a1 in 4 chance of having a congenitally deaf child.

31. No, Elsie will not be able to do this. If black and white feather colour is an example of co-dominance in these chickens, the genotype for black feathers is *BB*, the genotype for white feathers is *bb*, and the genotype for speckled feathers is *Bb*. The cross of a black rooster and a white hen will result in the genotypes shown in the Punnett square below.

	B	*b*
B	*BB*	*Bb*
b	*Bb*	*bb*

If Elsie crosses a speckled black and white chicken (*Bb*) with a white chicken (*bb*), she will still only get speckled black and white chickens or white chickens, as shown in the Punnett square below. She will not get any chickens that are white with a few black feathers, no matter how many crosses she performs.

	b	*b*
B	*Bb*	*Bb*
b	*bb*	*bb*

32. The babies and parents belong together as follows:

- Baby C: blood type AB. Parents 1: blood types A and B
- Baby D: blood type O. Parents 2: blood types O and O
- Baby A: blood type A. Parents 3: blood types AB and O
- Baby B: blood type B. Parents 4: blood types B and B

33. (a) The farmer should grow the seeds and cross-pollinate lemon trees that successfully grow in the cooler climate.

(b) A new variety of lemon could be produced if the gene(s) for growth in cooler climates could be isolated. Then, using restriction endonuclease enzymes, the gene(s) could be inserted in the egg cell or sperm nucleus of a lemon tree. Then the seed is planted.

(c) An advantage of artificial selection is that it is likely much easier and less expensive to do than genetically engineering the cooler climate gene(s). A disadvantage is that it may take a long time to achieve the desired result. It may require growing several generations of lemon trees and performing several cross-pollinations, with no guarantee that it will be successful.

An advantage of genetically engineering the desired lemon tree is that, assuming the gene(s) for growth in cooler climate can be isolated and introduced into a gamete, there is a good chance it will be successful. It will take less time than the many generations required for artificial selection. A disadvantage is that the process is likely to be much more expensive than artificial selection.

34. (a) Slipper limpets, which form stacks attached to seashore rocks, can change gender from male to female if necessary. When in a stack, the slipper limpet's gender is determined by a hormone which is constantly produced by the female. When the female dies, or becomes too old and stops producing the hormone, the male at the bottom of the stack will develop ovaries and become female. The process takes approximately 60 days. The genetic process that accounts for this is thought to be a protein that activates a particular gene. This gene codes for proteins that either form or stimulate hormones to change the male into a female, and begin producing eggs.

(b) Accept all reasonable responses. An example hypothesis is: If no female is present, one or more slipper limpets in an all-male stack will develop into females. An example of an experiment to test this hypothesis is: Place five adult male slipper limpets into one salt-water aquarium with suitable rock habitat. Put four adult males and one adult female into a similar aquarium. Mark the back of the shell of the female with non-toxic paint. The limpets should automatically organise themselves into a stack. Check the sexes of the limpets sixty days from the point of stack formation. If the hypothesis is correct, one or more males in the "all-male" stack should have developed into females. The sexes of the "four male–one female" stack should remain the same, with the original marked limpet still being the female.

35. (a) An amniocentesis may be performed as a prenatal screening, in which amniotic fluid containing some fetal cells is withdrawn from the amniotic sac. The cells are cultured, and the DNA can be tested to determine if the dwarfism gene is present. They may also opt for chorionic villi sampling, a technique that removes fetal cells for testing from the chorionic villus at the placenta. Ultrasound, which uses a high frequency sound that produces an image, will only show major growth aspects of fetal development and may, or may not, be helpful.

(b) The ethical question that accompanies prenatal screening is "What is the purpose of the screening?" If a screening determines that a fetus has a condition that results in an early death or a poor quality of life, the question of terminating the pregnancy is a possibility.

36. Liver, brain, and all somatic cells of the same individual that have a nucleus will have the same DNA because they originate from the same fertilized egg. The exception to this is that in females one of the X chromosomes of each cell is inactivated as a Barr body. So in effect, female tissues are a "mosaic" containing one of the two original X chromosomes in each cell.

Answers to Making Connections Questions

37. The flowchart or graphic organizer should contain the flowing points:

- Cigarette smoke contains several carcinogens.
- Smoking brings carcinogens into contact with the lining of the respiratory tract.
- Long term exposure to carcinogens increases the risk of them adversely affecting the cells of the respiratory tract.
- Carcinogens may cause cells that are actively reproducing to develop point mutations in their DNA.
- Over time, repeated DNA mutations may upset the genetic control of the cell cycle.
- A tumour may develop if the tissues repeatedly reproduce without a check on their growth.
- Tumours often interfere with the normal functions of the tissue.
- Cancer cells that become malignant in the original tissue may spread (metastasize) to other tissues and form secondary tumours.
- Localized lung tumours may be treated by surgical removal of the affected tissue.

38. Suggested possible answers are:

(a) It is not possible to change your genetic make-up, but with the correct information you can make wise lifestyle choices that will keep you as healthy as possible.

(b) Five headings could potentially be:

Introduction; Genetic Make-up; Diet; Exercise; and, Conclusion.

(c) The points under each heading may include:

- Introduction: After genes, it is environmental influences that count most.
- Genetic Make-up: Can you know your genetic make up? What is your family history? Do you have a genetic condition that you wish you did not? Could you pass that condition on to your children?
- Diet: Are we "what we eat?" Is a balanced diet enough? Can I be healthy being a vegan, a vegetarian, or …? New research was just released, and what was OK last week should be avoided this week—how to decide? What are trans fats, LDLs, HDLs, and good and bad cholesterol? Is there any "good" junk food?
- Exercise: Do I need a personal trainer? Should I belong to a gym? How much exercise and how often? What is right for me?
- Conclusion: Fish, fruits, vegetables, and exercise—will that do it? Will keeping healthy in these ways reduce my chances of mutations occurring in my DNA? What other things could I do to stay healthy and reduce my risks?

39. (a) The significance of the discovery of the herbicide-resistant weed depends on the genetic relationship and interaction between the weed and the canola. Will the presence of the weed make it difficult to grow canola? If this is the case, are there other herbicides that are safe to use with canola that are effective against the weed? How did the weed acquire resistance to the herbicide? Could the original research that produced the transgenic canola have predicted the occurrence of the herbicide resistant weed?

(b) Possible points that students may write are:

- The farmer worries if the weed will affect the quality and quantity of her canola crop. She worries

how she can control the weed without using herbicides that will reduce the market value of the canola.

- An official from the genetic engineering corporation that created the transgenic canola expresses his/her regrets that this happened. The company will work on a solution but that may be years away. The farmer is reimbursed for the cost of her canola seed and potential crop loss.
- The owner of a nearby organic farm is concerned about the possible use of herbicides on canola. If the herbicide should drift to his/her neighbouring crops, it may result in the loss of his/her organic crop designation.
- A consumer organization opposed to the development of genetically modified organisms wants the public to be informed about the health risks of consuming GMO food products. The organization is concerned whether the developers of the transgenic herbicide-resistant canola have researched the long term health effects of this product.
- A genetics researcher wants a grant from the genetic engineering corporation to study the weed and how it developed resistance to the herbicide.

40. Mendel would have likely become frustrated at the difficulties of using cats as a subject for investigating inheritance. Raising peas in significant numbers is much easier than raising cats. Finding observable traits in cats is more difficult than in pea plants. For example, the inheritance of colour in cats involves multiple alleles, and is far more complex than the traits selected in pea plants. Using a plant subject for studies in inheritance is much easier and more manageable than a vertebrate subject. It is doubtful that his studies would have had the same impact on our knowledge of inheritance had he used cats.

41. A detailed DNA analysis of a species can determine how biologically diverse it is. Such knowledge may help researchers determine if the species is more likely to become endangered in the future.

Several projects are also underway that collect and preserve eggs, semen, embryos, and DNA from endangered mammals, birds, and reptiles. The genetic material collected is saved for potential use in breeding projects aimed at reintroducing the species at risk.

42. (a) Optics, biochemistry and physics have opened genetics to analysis that was not possible until the past two centuries. Optics and the development of microscopes have permitted observation of chromosomes and their behaviour during mitosis and meiosis. Photography has allowed the production of karyotypes and helped determine the structure of DNA. Biochemistry and physics have made possible the separation of molecules in a protein gel that has an electric current applied to it.

(b) An understanding of gene interactions and the role of proteins in initiating and regulating gene expression would do much to further our present understanding of genetics.

Perhaps the unrelated field of electrochemistry would provide an understanding of what attracts proteins to certain genes and turns them on, while in other instances proteins turn genes off, or suppress their action. Accept any reasonable answer.

43. Genomics is the comprehensive study of the sequences, functions, and interactions of genes. Knowledge of biological diversity at the whole genome level may provide an understanding of the origins of individual traits and disease. Genetics refers to the study of single genes and their patterns of inheritance. It is less complex than genomics, which studies gene interactions. Human genetics provides an insight into specific genes and their role in human inheritance that can be used to further understanding and treatment of disease.

44. (a) The following are some questions that students may raise in terms of social effects of this technology: Should we invest in people who have more genetic potential or should we compensate those who have possibly less genetic potential? Would parents abort their child if knew that their developing embryo did not have genetic potential in terms of intelligence? Would they pay for gene therapy to insert this gene into the child's genome? Would this technology be used to create a "master" race? Would altering the gene for intelligence inadvertently alter or impact other genes? Is it ethical to value some traits over others? Could this technology lead to gene pollution – irreversibly altering this gene in the human population? Could this technology be used to treat people with brain injuries and/or dementia?

(b) Student answers will depend on their interests, values, and spirituality. For example, some will think that this type of biotechnology is playing "God" and that governments should make laws preventing this type of research. Other students may feel that the benefits of this type of research outweigh the risks and that governments should allow this type of research to continue while others simply will not care one way or the other. You may even find students note that most of the decision makers in government are not scientists and many will base their decision on emotion rather than on fact. Accept all reasonable answers.

(c) It is difficult to assess how students will respond to this question. Once again, you can expect a range of answers that depend on individual points of view. Some students may indicate that legislation should be enacted right away to prevent biotechnology research that involves humans. Others may indicate that educating individuals is important in making them

aware of the pros and cons of this type of research. Accept all reasonable answers.

45. Students' answers will reflect their beliefs. An example answer might be: Transgenic crops $0, gene therapy $60 million, cell cycle regulation $40 million. Transgenic crops have too many potential negative effects on the ecosystem. Gene therapy holds promise for treating genetic diseases. Cell cycle regulation holds promise of understanding and treating cancer and stopping the spread of malignant tumours.

46. Example answers are given:

Using transgenic pigs as organ donors	Benefits	Risks
To individual people	– treatment of disease	– long term use of anti-rejection drugs and side-effects are unknown
To society	– can help people live longer, and/or have a better quality of life	– ethical challenges might arise – possibility of infectious disease transferring from pigs to humans
To the economy	– less cost to care for people that are in ill health – they remain productive members of society – makes more money available for other medical research	– bearing the cost of potential adverse effects
To other species	– none	– none
To the environment	– none	– none

47. The structure and function of DNA is conserved across all species. Only the DNA of mitochondria and chloroplasts show variation in the genetic code.

48. Students' answers will reflect their beliefs. The application of molecular genetics for human use—either with transgenic organisms, or for the treatment of human diseases and conditions—may raise difficult and ethical questions about the appropriateness of the research and its subsequent application.

Molecular genetics and its manifestation in the great number of proteins and their complex interactions that occur in a cell and an organism may give one pause to ask, "Are these interactions all that there is to life?" We know that without these interactions there is no life. Yet seeds may remain dormant, but viable for thousands of years, and when exposed to the right conditions of water, nutrients, and sunlight, they germinate and grow. Viruses are often described as on the borderline between life and non-life. Are they nature's most complex molecules or nature's simplest life forms? They are mostly protein and nucleic acid. Without the conditions inside a cell, they are biologically inert, and are unable to convert molecules into a useable form of cellular energy or reproduce independently. They are, nevertheless, very much connected to the living world in a genetic and an evolutionary way. It is possible to appreciate the wonder and complexities of life without having a complete understanding of what it is.