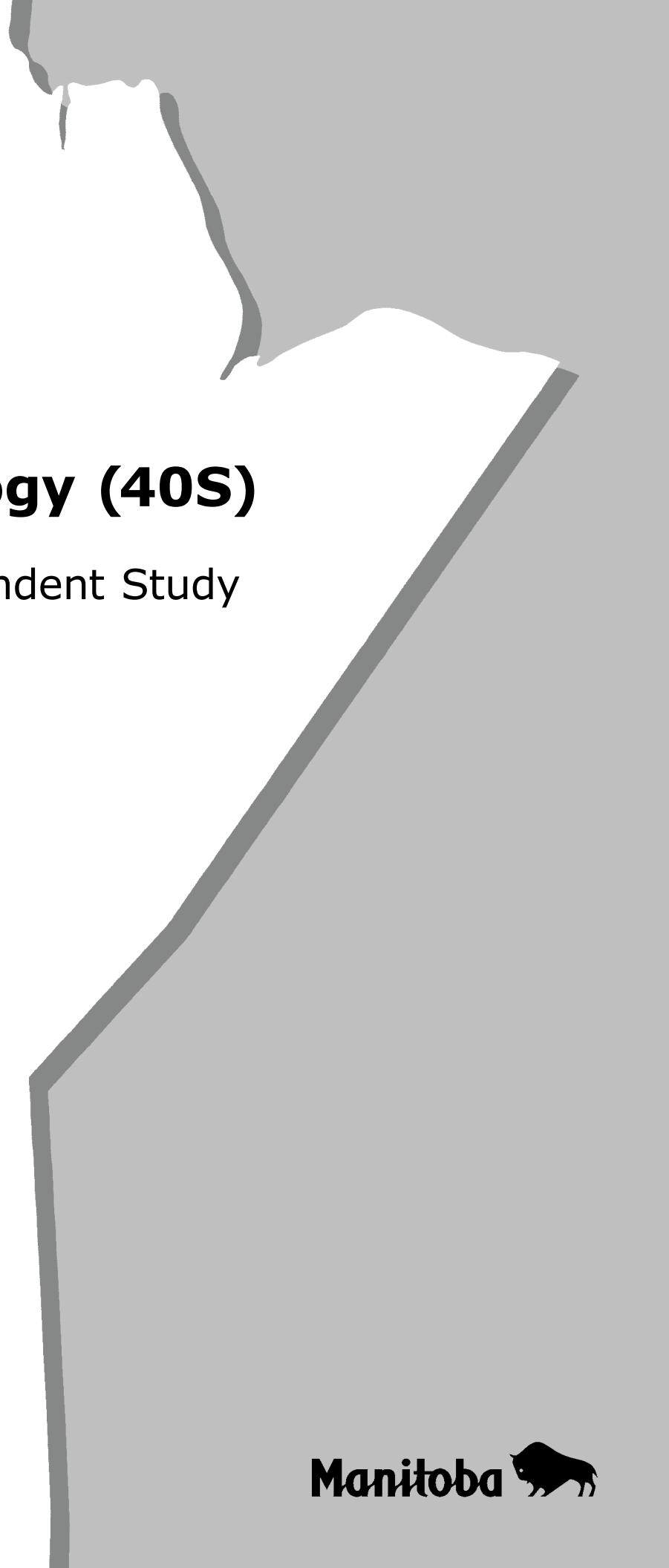
Grade 12 Biology (40S)

A Course for Independent Study



Manitoba

Grade 12 Biology (40S)

A Course for Independent Study

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CONTENTS

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Grade 12 Biology (40S)

Introduction

Introduction

Overview

Welcome to Grade 12 Biology: A Course for Independent Study. This course focuses on biological inheritance, evolutionary theory, and biodiversity.

As a student enrolled in a distance learning course, you have taken on a dual role—that of a student and a teacher. As a student, you are responsible for mastering the lessons and completing the learning activities and assignments. As a teacher, you are responsible for checking your work carefully, noting areas in which you need to improve and motivating yourself to succeed.

What Will You Learn in This Course?

In this course, you will learn about biological inheritance, evolutionary theory, and biodiversity. You will uncover the methods by which parents pass on traits to their offspring, focusing on how new lives are created and what forces determine an individual's appearance and capabilities. You will also explore how scientists classify living organisms and how they have revised classification systems in the wake of new discoveries, such as DNA and genomes.

How Is This Course Organized?

The Grade 12 Biology course consists of the following five modules:

- Module 1: Understanding Biological Inheritance
- Module 2: Mechanisms of Inheritance
- Module 3: Evolutionary Theory and Biodiversity
- Module 4: Organizing Biodiversity
- Module 5: Conservation of Biodiversity

Each module in this course consists of several lessons. In each lesson, you will read a few pages and then complete a learning activity and an assignment. Some lessons require you to do some investigative research or observation work in the community.

The lessons in this course are organized as follows:

- **Lesson Focus:** The Lesson Focus at the beginning of each lesson identifies one or more specific learning outcomes (SLOs) that are addressed in the lesson. The SLOs identify the knowledge and skills you should have achieved by the end of the lesson. For a complete list of the SLOs identified for Grade 12 Biology, refer to the Appendix at the end of this course.
- **Introduction:** Each lesson begins by outlining what you will be learning in that lesson.
- **Lesson:** The main body of the lesson consists of the content and processes that you need to learn. It contains information, explanations, diagrams, and completed examples.
- **Learning Activities:** Each lesson has a learning activity that focuses on the lesson content. Your responses to the questions in the learning activities will help you to practise or review what you have just learned. Once you have completed a learning activity, check your responses with those provided in the Learning Activity Answer Key found at the end of the applicable module. Do not send your learning activities to the Distance Learning Unit for assessment.
- **Assignments:** An assignment is found at the end of each lesson within this course. At the end of each module, you will mail or electronically submit all your completed assignments from that module to the Distance Learning Unit for assessment. All assignments combined will be worth a total of 60 percent of your final mark in this course.
- **Lesson Summary:** Each lesson ends with a brief review of what you just learned.

What Resources Will You Need for This Course?

To complete this course, you should have access to the following:

- Make sure you have a notebook for recording your responses to learning activities.
- You will need access to books, magazines, newspapers, and/or the Internet to find information about a variety of topics for your assignments:
  - In Assignment 2.1, you will compare several scientists and their contributions to science.
  - In Assignment 2.5, you will examine the application of gene technology in either biological resource management or human health and welfare.
  - In Assignment 4.2, you will do some research on North American bear species.
  - In Assignment 5.4, you will research an environmental issue of your choice and write a paper on your findings.

- You will also need some materials for investigations:
  - For Learning Activity 5.3, you will need a textbook, a ruler, and a microscope cover slip (or index card).
  - For Assignment 5.3, you will need white rice (uncooked), a marker, a calculator, and a clean tin can or jar with a lid.

Who Can Help You with This Course?

Taking an independent study course is different from taking a course in a classroom. Instead of relying on the teacher to tell you to complete a learning activity or an assignment, you must tell yourself to be responsible for your learning and for meeting deadlines. There are, however, two people who can help you be successful in this course: your tutor/marker and your learning partner.

Your Tutor/Marker

Tutor/markers are experienced educators who tutor independent students and mark assignments and examinations. When you are having difficulty with something in this course, be sure to contact your tutor/marker, who is there to help you. Your tutor/marker's name and contact information were sent to you with this course. Your tutor/marker information is also available in the learning management system (LMS).

Your Learning Partner

A learning partner is someone **you choose** who will help you learn. It may be someone who knows something about science, but it doesn't have to be. A learning partner could be someone else who is taking this course, a teacher, a parent or guardian, a sibling, a friend, or anybody else who can help you. Most importantly, a learning partner should be someone with whom you feel comfortable, and who will support you as you work through this course.

Your learning partner can help you keep on schedule with your course work, read the course with you, check your work, look at and respond to your learning activities, or help you make sense of assignments. You may even study for your examinations with your learning partner. If you and your learning partner are taking the same course, however, your assignment work should not be identical.

Plagiarism

Plagiarism IS a big deal with serious consequences, so it's important that you understand what it is and how to avoid it.

What is plagiarism?

In brief, plagiarism is taking someone's ideas or words and presenting them as if they are your own.

How can you avoid plagiarism?

- Begin early. Research takes time. Allow enough time to search for, evaluate, and read sources, and to get help if you need it. Always document your sources immediately.
- Present your research by quoting and paraphrasing.
  - When you use a quote, you use the exact same words with quotation marks, and you indicate exactly where it came from.
  - When you paraphrase, you rewrite an author's idea using your own words and you do not use quotation marks (but you also make sure to state clearly whose idea it is).
- Learn how to use different citation styles. (Refer to Assignment 5.4 for information on how to cite references.)
- Give credit where credit is due. Never pretend someone else's idea is your own.

How Will You Know How Well You Are Learning?

You will know how well you are learning in this course by how well you complete the learning activities, assignments, and examinations.

Learning Activities

The learning activities in this course will help you to review and practise what you have learned in the lessons. You will not submit the completed learning activities to the Distance Learning Unit. Instead, you will complete the learning activities and compare your responses to those provided in the Learning Activity Answer Key found at the end of each module.

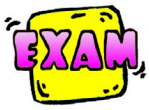
Make sure you complete the learning activities. Doing so will not only help you to practise what you have learned, but will also prepare you to complete your assignments and the examination(s) successfully. Many of the questions on the examination(s) will be similar to the questions in the learning activities. Remember that you **will not submit learning activities to the Distance Learning Unit**.

Assignments

At the end of each lesson, you will complete an assignment. Once you have completed all the assignments in a module, you will submit them to the Distance Learning Unit for assessment. The assignments are worth a total of 60 percent of your final course mark.

The tutor/marker will mark your assignments and return them to you. Remember to keep all marked assignments until you have finished the course so that you can use them to study for your examinations.

Midterm and Final Examinations



This course contains a midterm examination and a final examination.

- The **midterm examination** is based on Modules 1 and 2, and is worth 20 percent of your final course mark. You will write the midterm examination when you have completed Module 2.
- The **final examination** is based on Modules 3, 4, and 5, and is worth 20 percent of your final course mark. You will write the final examination when you have completed Module 5.

The two examinations are worth a total of 40 percent of your final course mark. You will write both examinations under supervision.

Examination review lessons are found at the end of Modules 2 and 5. To do well on each examination, you should review all the work you have completed from the modules, including all learning activities and assignments.

Requesting Your Examinations

You are responsible for making arrangements to have the examinations sent to your proctor from the Distance Learning Unit. Please make arrangements before you finish Module 2 to write the midterm examination. Likewise, you should begin arranging for your final examination before you finish Module 5.

To write your examinations, you need to make the following arrangements:

- **If you are attending school,** your examination will be sent to your school as soon as all the applicable assignments have been submitted. You should make arrangements with your school's Independent Study Option (ISO) school facilitator to determine a date, time, and location to write the examination.

- **If you are not attending school,** check the **Examination Request Form** for options available to you. Examination Request Forms can be found on the Distance Learning Unit's website, or look for information in the learning management system (LMS). **Two weeks before** you are ready to write the examination, fill in the Examination Request Form and mail, fax, or email it to

  Distance Learning Unit
  500–555 Main Street
  P.O. Box 2020
  Winkler, MB R6W 4B8
  Fax: 204-325-1719
  Toll-Free Telephone: 1-800-465-9915
  Email: distance.learning@gov.mb.ca

How Much Time Will You Need to Complete This Course?

Learning through independent study has several advantages over learning in the classroom. You are in charge of how you learn and you can choose how quickly you will complete the course. You can read as many lessons as you wish in a single session. You do not have to wait for your teacher or classmates.

From the date of your registration, you have a maximum of **12 months** to complete this course, but the pace at which you proceed is up to you. Read the following charts for suggestions on how to pace yourself.

Chart A: Semester 1

If you want to start the course in September and complete it in January, you can follow the timeline suggested below.

Module	Completion Date
Module 1	End of September
Module 2	End of October
Midterm Examination	Middle of November
Module 3	End of November
Module 4	End of December
Module 5	Middle of January
Final Examination	End of January

Chart B: Semester 2

If you want to start the course in February and compete it in May, you can follow the timeline suggested below.

Module	Completion Date
Module 1	Middle of February
Module 2	End of February
Midterm Examination	Middle of March
Module 3	End of March
Module 4	Middle of April
Module 5	End of April
Final Examination	Middle of May

Chart C: Full School Year (Not Semestered)

If you want to start the course in September and compete it in May, you can follow the timeline suggested below.

Module	Completion Date
Module 1	End of September
Module 2	End of October
Midterm Examination	End of November
Module 3	End of January
Module 4	Beginning of March
Module 5	Middle of April
Final Examination	Middle of May

Timelines

Do not wait until the last minute to complete your work, since your tutor/marker may not be available to mark it immediately. It may take a few weeks for your tutor/marker to assess your work and return it to you.

If you need this course to graduate this school year, all coursework must be received by the Distance Learning Unit on or before the first Friday in May, and all examinations must be received by the Distance Learning Unit on or before the last Friday in May. Any coursework or examinations received after these deadlines may not be processed in time for a June graduation. Assignments or examinations submitted after these recommended deadlines will be processed and marked as they are received.

When and How Will You Submit Completed Assignments?

When to Submit Assignments

While working on this course, you will submit completed assignments to the Distance Learning Unit five times. The following chart shows you exactly what assignments you will be submitting at the end of each module.

Submission of Assignments	
Submission	Assignments You Will Submit
1	**Module 1: Understanding Biological Inheritance** Module 1 Cover Sheet Assignment 1.1: Introduction to Genetics Assignment 1.2: Making Predictions in Genetics Assignment 1.3: Sex-Linked Traits Assignment 1.4: Pedigree Charts and Genetic Testing Assignment 1.5: Nondisjunction and Karyotypes
2	**Module 2: Mechanisms of Inheritance** Module 2 Cover Sheet Assignment 2.1: The Discovery of DNA Assignment 2.2: The Structure of DNA Assignment 2.3: Replication, Transcription, and Translation Assignment 2.4: Genetic Mutations Assignment 2.5: Applications of Genetic Knowledge
3	**Module 3: Evolutionary Theory and Biodiversity** Module 3 Cover Sheet Assignment 3.1: Science and Evolution Assignment 3.2: Theories of Evolutionary Change Assignment 3.3: Adaptation Assignment 3.4: Population Genetics Assignment 3.5: Evolution and Speciation

continued

Submission of Assignments (continued)	
Submission	Assignments You Will Submit
4	**Module 4: Organizing Biodiversity** Module 4 Cover Sheet Assignment 4.1: Biodiversity Assignment 4.2: North American Bear Species Assignment 4.3: Systems of Classification Assignment 4.4: The Three Domains of Life Assignment 4.5: Evolutionary Trends
5	**Module 5: Conservation of Biodiversity** Module 5 Cover Sheet Assignment 5.1: Viewpoints on Maintaining Biodiversity Assignment 5.2: Sustainability of the Boreal Forest Assignment 5.3: Mark and Recapture Sampling Assignment 5.4: An Environmental Issue in Manitoba (Research Paper)

How to Submit Assignments

In this course, you have the choice of submitting your assignments either by mail or electronically.

- **Mail:** Each time you **mail** something, you must include the print version of the applicable Cover Sheet (found at the end of this Introduction). Complete the information at the top of each Cover Sheet before submitting it along with your assignments.
- **Electronic submission:** You do not need to include a cover sheet when submitting assignments electronically.

Submitting Your Assignments by Mail

If you choose to mail your completed assignments, please photocopy all the materials first so that you will have a copy of your work in case your package goes missing. You will need to place the applicable module Cover Sheet and assignment(s) in an envelope, and address it to

Distance Learning Unit
500–555 Main Street
P.O. Box 2020
Winkler MB R6W 4B8

Your tutor/marker will mark your work and return it to you by mail.

Submitting Your Assignments Electronically

Assignment submission options vary by course. Sometimes assignments can be submitted electronically and sometimes they must be submitted by mail. Specific instructions on how to submit assignments were sent to you with this course. In addition, this information is available in the learning management system (LMS).

If you are submitting assignments electronically, make sure you have saved copies of them before you send them. That way, you can refer to your assignments when you discuss them with your tutor/marker. Also, if the original hand-in assignments are lost, you are able to resubmit them.

Your tutor/marker will mark your work and return it to you electronically.

The Distance Learning Unit does not provide technical support for hardware-related issues. If troubleshooting is required, consult a professional computer technician.

What Are the Guide Graphics For?

Guide graphics are used throughout this course to identify and guide you in specific tasks. Each graphic has a specific purpose, as described below.

Lesson Focus/Specific Learning Outcomes (SLOs): Note that these SLOs will be addressed within the lesson. (A complete list of the Grade 12 Biology SLOs can be found in the Appendix at the end of this course.)

Internet: Use the Internet, if you have access to it, to obtain more information. Internet access is optional for this course.

Learning Partner: Ask your learning partner to help you with this task.

Learning Activity: Complete a learning activity. This will help you to review or practise what you have learned and to prepare for an assignment or an examination. You will not submit learning activities to the Distance Learning Unit. Instead, you will compare your responses to the Learning Activity Answer Keys found at the end of the applicable module.

Check Your Work: Check your responses against those provided in the Learning Activity Answer Key found at the end of the applicable module.

Assignment: Complete an assignment. You will submit your completed assignments to the Distance Learning Unit for assessment. You will be submitting your assignments at the end of every module.

Mail or Electronic Submission: Mail or electronically submit your completed assignments to the Distance Learning Unit for assessment at this time.

Examination: Write your midterm or final examination at this time.

Note: Take note of and remember this important information or reminder.

Remember: If you have questions or need help at any point during this course, contact your tutor/marker or ask your learning partner for help.

Good luck with the course!

Notes

Grade 12 Biology (40S)

Module 1 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

Drop-off/Courier Address

Distance Learning Unit
555 Main Street
Winkler MB R6W 1C4

Mailing Address

Distance Learning Unit
500–555 Main Street
PO Box 2020
Winkler MB R6W 4B8

Contact Information

Legal Name: _____ Preferred Name: _____

Phone: _____ Email: _____

Mailing Address: _____

City/Town: _____ Postal Code: _____

Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Module 1 Assignments Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	**Attempt 1** _____ Date Received	**Attempt 2** _____ Date Received
❑ Assignment 1.1: Introduction to Genetics	_____ /41	_____ /41
❑ Assignment 1.2: Making Predictions in Genetics	_____ /38	_____ /38
❑ Assignment 1.3: Sex-Linked Traits	_____ /44	_____ /44
❑ Assignment 1.4: Pedigree Charts and Genetic Testing	_____ /39	_____ /39
❑ Assignment 1.5: Nondisjuntion and Karyotypes	_____ /13	_____ /13
	Total: ___ /175	**Total: ___ /175**
For Tutor/Marker Use		
Remarks:		

Grade 12 Biology (40S)

Module 2 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

Drop-off/Courier Address

Distance Learning Unit
555 Main Street
Winkler MB R6W 1C4

Mailing Address

Distance Learning Unit
500–555 Main Street
PO Box 2020
Winkler MB R6W 4B8

Contact Information

Legal Name: _____ Preferred Name: _____

Phone: _____ Email: _____

Mailing Address: _____

City/Town: _____ Postal Code: _____

Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Module 2 Assignments Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	**Attempt 1** _____ Date Received	**Attempt 2** _____ Date Received
❑ Assignment 2.1: The Discovery of DNA	_____ /20	_____ /20
❑ Assignment 2.2: The Structure of DNA	_____ /24	_____ /24
❑ Assignment 2.3: Replication, Transcription, and Translation	_____ /35	_____ /35
❑ Assignment 2.4: Genetic Mutations	_____ /36	_____ /36
❑ Assignment 2.5: Applications of Genetic Knowledge	_____ /28	_____ /28
	Total: ___ /143	**Total: ___ /143**
For Tutor/Marker Use		
Remarks:		

Grade 12 Biology (40S)

Module 3 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

Drop-off/Courier Address

Distance Learning Unit
555 Main Street
Winkler MB R6W 1C4

Mailing Address

Distance Learning Unit
500–555 Main Street
PO Box 2020
Winkler MB R6W 4B8

Contact Information

Legal Name: _____ Preferred Name: _____

Phone: _____ Email: _____

Mailing Address: _____

City/Town: _____ Postal Code: _____

Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Module 3 Assignments Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	**Attempt 1** _____ Date Received	**Attempt 2** _____ Date Received
❑ Assignment 3.1: Science and Evolution	_____ /20	_____ /20
❑ Assignment 3.2: Theories of Evolutionary Change	_____ /20	_____ /20
❑ Assignment 3.3: Adaptation	_____ /15	_____ /15
❑ Assignment 3.4: Population Genetics	_____ /22	_____ /22
❑ Assignment 3.5: Evolution and Speciation	_____ /18	_____ /18
	Total: ___ /95	**Total: ___ /95**

For Tutor/Marker Use
Remarks:

Grade 12 Biology (40S)

Module 4 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

Drop-off/Courier Address

Distance Learning Unit
555 Main Street
Winkler MB R6W 1C4

Mailing Address

Distance Learning Unit
500–555 Main Street
PO Box 2020
Winkler MB R6W 4B8

Contact Information

Legal Name: _____ Preferred Name: _____

Phone: _____ Email: _____

Mailing Address: _____

City/Town: _____ Postal Code: _____

Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Module 4 Assignments Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	**Attempt 1** _____ Date Received	**Attempt 2** _____ Date Received
❑ Assignment 4.1: Biodiversity	_____ /9	_____ /9
❑ Assignment 4.2: North American Bear Species	_____ /22	_____ /22
❑ Assignment 4.3: Systems of Classification	_____ /12	_____ /12
❑ Assignment 4.4: The Three Domains of Life	_____ /15	_____ /15
❑ Assignment 4.5: Evolutionary Trends	_____ /10	_____ /10
	Total: ___ /68	**Total: ___ /68**
For Tutor/Marker Use		
Remarks:		

Grade 12 Biology (40S)

Module 5 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

Drop-off/Courier Address

Distance Learning Unit
555 Main Street
Winkler MB R6W 1C4

Mailing Address

Distance Learning Unit
500–555 Main Street
PO Box 2020
Winkler MB R6W 4B8

Contact Information

Legal Name: _____ Preferred Name: _____

Phone: _____ Email: _____

Mailing Address: _____

City/Town: _____ Postal Code: _____

Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Module 5 Assignments Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	**Attempt 1** _____ Date Received	**Attempt 2** _____ Date Received
❑ Assignment 5.1: Viewpoints on Maintaining Biodiversity	_____ /20	_____ /20
❑ Assignment 5.2: Sustainability of the Boreal Forest	_____ /20	_____ /20
❑ Assignment 5.3: Mark and Recapture Sampling	_____ /20	_____ /20
❑ Assignment 5.4: An Environmental Issue in Manitoba (Research Paper)	_____ /35	_____ /35
	Total: ___ /95	**Total: ___ /95**
For Tutor/Marker Use		
Remarks:		

Assignment 5.4: An Environmental Issue in Manitoba (Research Paper)		
Assessment Criteria		
Criteria		Marks
Length	Paper may be typed or handwritten. ■ Typed: At least three double-spaced typewritten pages, in a font no larger than 12 point. ■ Handwritten: Of a similar length and format.	_____ /5
Cover sheet	■ Includes the title of the paper, the student's name, and the date.	_____ /1
Topic	■ Gives a clear statement of the environmental issue selected (must be one of the issues identified in Learning Activity 5.4).	_____ /2
Content	■ Provides a clear explanation of why the issue is important in Manitoba. ■ Considers events and perspectives from the past that contributed to the current importance of the issue. ■ **Explains different viewpoints on the issue.**	_____ /12
Personal stand	■ States personal viewpoint on the issue. ■ Includes a rationale for the viewpoint taken.	_____ /5
Future implications	■ States what the future may hold with respect to the issue. ■ Gives reasons for the prediction.	_____ /5
References	■ Includes at least three different sources, at least two of which are sources other than encyclopedias. ■ Follows the specified reference style.	_____ /5
	Total	_____ /35

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Grade 12 Biology (40S)

Module 1
Understanding Biological Inheritance

Module 1:
Understanding Biological Inheritance

Introduction

Did you know that a male lion and a female tiger can mate and produce an offspring called a liger? Interestingly, male ligers are sterile and cannot produce offspring, while female ligers are often fertile. Ligers resemble lions much more than they resemble tigers. However, like tigers, ligers like to swim, a behaviour that goes against a lion's nature. Also, a liger is much larger as an adult than either of its parents.

How can these realities be explained?

In the first module of this course, you will learn about how traits are passed from parents to offspring in the biological world. All living things, from microbes to mammals, carry genetic information that determines the great diversity of form and function in the life forms on Earth.

Module 1 Assignments

When you have completed the assignments for Module 1, submit your completed assignments to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 1.1	Introduction to Genetics
2	Assignment 1.2	Making Predictions in Genetics
3	Assignment 1.3	Sex-Linked Traits
4	Assignment 1.4	Pedigree Charts and Genetic Testing
5	Assignment 1.5	Nondisjunction and Karyotypes

Notes

Lesson 1: Introduction to Genetics

Lesson Focus

In this lesson, you will

- ❑ outline Gregor Mendel's principles of inheritance, stating their importance to the understanding of heredity

  Include: principles of segregation, dominance, and independent assortment

- ❑ explain what is meant by the terms *heterozygous* and *homozygous*
- ❑ distinguish between *genotype* and *phenotype*, and use these terms appropriately when discussing the outcomes of genetic crosses

Introduction

Have you ever wondered why human eye colour can vary so much? It is rarely easy to predict a child's eye colour correctly based on knowledge about the eye colour of that child's parents. And yet, the child will resemble his or her parents in many ways. Why are some children born with traits that neither parent possesses? Why do some children look more like their fathers than like their mothers? These are only a few questions about how humans pass their traits from one generation to the next. And humans are only one of the millions of species on Earth.

In this lesson, you will learn about the work of Gregor Mendel (1822–1884). His ideas about inheritance serve as the foundation of current understanding of genetics. Mendel drew some amazing conclusions about inheritance without ever knowing how or where the "instructions" for inherited traits were packaged in the cells of living things.

You will also learn principles of genetics that were discovered after the time of Mendel. Genetics is an area of study that has grown since Mendel's time and continues to grow now as new discoveries are made.

The Work of Gregor Mendel

The story of Gregor Mendel and his work provides a fascinating glimpse into the nature of science. Mendel, shown in Figure 1.1, was born in 1822 and, as a young man, attended the University of Vienna. There he studied chemistry, biology, and physics, but left the university before graduating, probably for health reasons. He entered the Augustinian monastery in Brno (Brünn) and, with the support of the abbot, began his investigation of the inheritance of certain traits in pea plants (*Pisum sativum*). His choice of pea plants as the experimental subject was fortunate, as peas grow and reproduce quickly, their mating can be easily controlled, and the plants have a number of distinct traits that are readily observed.

Over the course of the next eight years, Mendel conducted experiments and maintained detailed records of his results. His university training led him to design simple experiments that permitted him to observe the inheritance of one trait at a time. His use of mathematics allowed him to formulate conclusions based on his results.

Mendel presented his conclusions in a paper entitled "Experiments in Plant Hybridization" at a meeting of the Association for Natural Research in Brno in 1865. The scientific community of the time did not seem to grasp the significance of Mendel's work. As a result, it was largely ignored. Mendel abandoned his research upon his election as abbot in 1868, due in part to his heavy workload, as well as to the lack of recognition for his research. Gregor Mendel died in 1884, not knowing whether the world would acknowledge the importance of his work.

It was not until 1900 that the inheritance concepts put forth by Gregor Mendel were again found to be supported by experimental data. In that year, three scientists working independently of one another rediscovered and confirmed Mendel's laws or principles of inheritance. Hugo de Vries, Carl Correns, and Erich von Tschermak-Seysenegg gave credit to Gregor Mendel in the publications of their papers, thereby giving him the recognition he long deserved.

Figure 1.1 **Gregor Mendel**

Photo credit: Bettmann/CORBIS

Source: Biggs, Alton, et al. *Glencoe Science Biology*. Columbus, OH: Glencoe/McGraw-Hill, 2009. 277.

Mendel's Fundamental Laws of Inheritance

Remember that Mendel's conclusions were based on his own experiments with garden peas at the monastery in which he lived. His ideas were clearly based on mathematical analyses of his experimental results. He had no preconceptions about chromosomes, genes, or deoxyribonucleic acid (DNA).

Mendel's conclusions, based on detailed records of the results of his experiments, are known as Mendel's laws or principles of inheritance, which are summarized below.

- **The law of dominance:** Mendel found that some traits have the ability to mask other traits when both traits appear in the parents. For example, he found that it was possible for pea plants with red flowers to be crossed with pea plants with white flowers and get, in the offspring, only pea plants with red flowers. Apparently, the information for white flowers was being ignored in the offspring. Mendel believed that each pea plant possesses two factors for each trait in each cell. (The current name for *factor* is *gene*.) One of those factors came from the plant's female parent and the other from the plant's male parent. Mendel found that *dominance* actually occurs regularly in the normal traits of garden peas. For example, tall is dominant over short in pea plants. The trait that is expressed is called the *dominant* trait and the one that is covered up is called the *recessive* trait.

- **The law of segregation:** During the formation of reproductive cells, egg and sperm, the paired factors separate or segregate from one another; the offspring, as a result, receives a random assortment of genes for different traits from its parents. For example, if a pea plant received a factor for red flowers from its female parent and a factor for white flowers from its male parent, that plant would possess two factors for flower colour. In this case, one factor covers up the other factor so that it is not expressed.
- **The law of independent assortment:** During the formation of egg and sperm, segregating pairs of factors assort independently of each other. (You will learn more about this law in Lesson 2 of Module 1.)

Basic Concepts of Genetics

A number of terms used in the study of genetics are fundamental to a solid understanding of how inheritance occurs. These terms include the following:

allele

Refers to the different forms that a given gene can take. For example, if there were two types of genes for flower colour in pea plants, the gene coding for red flowers could be represented by the allele *R*. Typically, dominant alleles are represented by upper case letters and recessive alleles by lower case letters. The allele coding for white flowers in pea plants could be represented by the allele *r* because it is recessive.

chromosome

The structure in living cells that carries genetic information. One chromosome carries many genes.

diploid cell

A cell possessing two genes for every trait. In humans, the diploid chromosome number is 46. Most human body cells are diploid.

gamete

A haploid sex cell such as an egg cell or a sperm cell.

gene

The current name for Mendel's term *factor*. Genes are responsible for the traits that are expressed in the individual.

genotype

The particular genes that an organism possesses for a given trait. The genotype of a diploid organism will consist of two factors, one from each of that organism's parents. The genotype of a haploid gamete consists of only one factor.

haploid cell

A cell possessing only one gene for every trait. In humans, the haploid chromosome number is 23. Egg and sperm cells are haploid cells.

heterozygous

Possessing different alleles for a trait. A heterozygous genotype is one in which the two alleles present are not identical. *Rr* is a heterozygous genotype.

homozygous

Possessing identical alleles for a trait. A homozygous genotype is one in which the two alleles present are identical. *RR* is a homozygous genotype.

hybrid

An offspring possessing two different alleles for a given trait. One of these alleles may be dominant over the other. For example, a pea plant hybrid for flower colour would have the genotype *Rr*, and the phenotype red flowers.

maternal chromosome

In a diploid organism, the chromosome in each pair that originated in that organism's female parent; it was located in the egg cell at the time of fertilization.

meiosis

The type of cell division in which the chromosome number is reduced from diploid to haploid. Meiosis results in the production of gametes—egg and sperm cells.

mitosis

The type of cell division in which the chromosome number is preserved. Diploid cells reproduce by mitosis to produce more identical diploid cells.

paternal chromosome

In a diploid organism, the chromosome in each pair that originated in that organism's male parent; it was located in the sperm cell at the time of fertilization.

phenotype

The particular trait expressed in a given organism. This trait can be either structural or functional. Phenotype results from genotype.

Punnett square

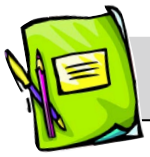
A tool used to predict the offspring of a cross between two particular parental organisms. Punnett squares clearly illustrate Mendel's principle of segregation and principle of independent assortment.

purebred

An offspring in which the two alleles for a trait are identical.

zygote

The diploid cell that is formed when two haploid cells join in fertilization.



Learning Activity 1.1: Introduction to Genetics

This learning activity will give you an opportunity to review and practise what you have learned in this lesson. Please record your responses in your notebook.

1. Assume that, in garden peas, round seeds are the dominant trait and wrinkled seeds are the recessive trait. The alleles for this trait are *R* for round and *r* for wrinkled.
   a) What is the genotype of a plant with wrinkled seeds?
   b) What is the genotype of a plant with round seeds?
   c) What is the genotype of a hybrid plant?
   d) What is the genotype of a purebred plant?
   e) What is the genotype of a heterozygous plant?
   f) What is the genotype of a homozygous plant?
   g) What is the genotype of a homozygous dominant plant?
   h) What is the phenotype of a hybrid plant?
   i) What is the phenotype of a homozygous recessive plant?
   j) If a parent plant with the genotype *Rr* produces gametes, what genes will the gametes carry?
   k) If a plant has the genotype *Rr*, did it receive the *R* allele or the *r* allele from its female parent?
2. Name the three laws of inheritance that Gregor Mendel discovered while studying pea plants. Briefly define each law.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 1.1. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about the fundamental concepts of genetics first suggested by Gregor Mendel. In particular, Mendel stated three laws of inheritance, which are still useful today. You also learned several definitions of terms that are commonly used in genetics. Understanding these terms will help you as you continue to study genetics in the lessons that follow.

In the next lesson, you will learn how to predict the genotypes of the offspring that a given pair of parents can produce; you will learn to make such predictions using a tool called a *Punnett square*.

You will also learn that not all traits are controlled by dominant and recessive alleles. In some traits, two alleles are possible and, when both are present, both are shown in the phenotype of that individual. In other traits, more than two alleles are possible—although each individual organism still possesses only two alleles in its body cells.

Notes

Assignment 1.1: Introduction to Genetics (41 marks)

Please respond to the following assignment questions in the space provided. Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 1.

1. In some breeds of dogs, black fur colour is dominant over yellow fur colour. Call these alleles *B* and *b*. *(10 marks total—2 marks for each question)*

   a) What two genotypes are possible for a dog that has black fur?

   _____

   b) What is the one genotype for a dog that has yellow fur?

   _____

   c) If the male parent has genotype *Bb*, what two types of sperm cells can he produce?

   _____

   d) If the female parent has genotype *BB*, what type of egg cell can she produce?

   _____

   e) Is it possible for the two dogs from questions (c) and (d) to produce yellow puppies? Why or why not?

   _____

   _____

(continued)

Assignment 1.1: Introduction to Genetics (continued)

2. Mendel worked with many traits of garden peas. Six traits that he studied are given below. Use the information provided to answer the questions that follow. *(20 marks total—2 marks per question)*

Trait	**Dominant**	**Recessive**
Seed shape:	Round (*R*)	Wrinkled (*r*)
Seed colour:	Yellow (*Y*)	Green (*y*)
Pod shape:	Smooth (*S*)	Wrinkled (*s*)
Pod colour:	Green (*C*)	Yellow (*c*)
Flower position:	Axial (*A*)	Terminal (*a*)
Stem length:	Tall (*T*)	Short (*t*)

a) What is the genotype of a purebred plant that produces axial flowers?

_____

b) What is the genotype of a plant that is hybrid for seed colour?

_____

c) What is the phenotype of a plant that has genotype *Cc*?

_____

d) What is the phenotype of a plant that is homozygous recessive for stem length?

_____

e) What is the genotype of a plant that is heterozygous for pod shape?

_____

f) What is the phenotype of a plant that is heterozygous for pod colour?

_____

g) What types of gametes can a plant that is purebred for smooth pod shape produce?

_____

(continued)

h) What is the genotype of a short plant?

_____

i) Do plants that are heterozygous for flower position have axial flowers or terminal flowers?

_____

j) What three possible genotypes can a pea plant possess for seed colour?

_____

3. In some breeds of dogs, the hairless condition is dominant over the hairy condition. Explain how it is possible for two dogs that are hairless to produce a puppy that is hairy. *(5 marks)*

_____

_____

_____

_____

_____

_____

_____

_____

(continued)

Assignment 1.1: Introduction to Genetics (continued)

4. Name and briefly explain Mendel's three laws of inheritance. *(6 marks)*

Lesson 2: Making Predictions in Genetics

Lesson Focus

In this lesson, you will

- ❑ use Punnett squares to solve a variety of autosomal inheritance problems, and justify the results using appropriate terminology

  Include: monohybrid cross, dihybrid cross, test cross, P generation, F_1 generation, F_2 generation, phenotypic ratio, genotypic ratio, dominant alleles, recessive alleles, purebred, hybrid, and carrier

- ❑ describe examples of and solve problems involving the inheritance of phenotypic traits that do not follow a dominant-recessive pattern

  Examples: co-dominance, incomplete dominance, multiple alleles, lethal genes . . .

Introduction

In the previous lesson, you learned about Gregor Mendel's study of pea plants and about the three laws of inheritance that followed from his work. You learned some of the basic terminology used in the study of genetics. You are now ready to look at how you can make predictions about the offspring that can be produced from a particular pair of parents. You are ready to solve genetics problems that deal with *crosses* between parents whose genotypes and phenotypes may or may not be known.

Mendel's three laws of inheritance started out as hunches as Mendel conducted his study of garden peas. As extensive amounts of experimental data began to validate his hunches, they became more strongly supported ideas. When his ideas were used to make predictions that were then supported repeatedly through experimentation, those ideas became laws of genetics. Scientific ideas that are used to make predictions that are then tested through experimentation are powerful tools for trying to understand the biological world.

In this lesson, you will learn to use Punnett squares to make predictions about the outcome of genetics crosses. You will also learn about traits that do not follow the law of dominance. Fortunately for Mendel, the traits in pea plants that he studied did follow the law of dominance. In nature, however, many traits are not controlled by dominant and recessive alleles.

Punnett Squares

The *Punnett square* (developed by Reginald Punnett) is a tool you will use to understand how the alleles present in parental organisms are passed on to their offspring.

Review of Genetics Concepts and Conventions

Before you look at how Punnett squares are used, you will review some basic genetics concepts and conventions that will be useful to keep in mind.

- Each *diploid* individual organism possesses *two copies* of each gene. These copies do not need to be identical to each other. The individual received one gene from its father and one gene from its mother. Each gene can exist in various forms, called *alleles* in genetics.
- Gametes possess *one copy* of each gene. Gametes are *haploid* as a result. Which one of the two alleles present in the adult passes into a particular gamete is determined by chance during meiosis.
- Mendel's three laws of inheritance are important foundations for the study of genetics; however, the inheritance of some traits does not follow the law of dominance.
- Conventionally, a heterozygous genotype is written as *Rr* instead of *rR*. Uppercase and lowercase letters are used together only if one allele is dominant over the other allele.
- An individual that is heterozygous for a trait can also be called a *carrier* of the recessive allele. A carrier possesses the recessive allele, does not show that recessive trait, but does pass the recessive allele to its offspring through roughly 50 percent of its gametes.
- When a cross is made between two individual organisms, the two that are crossed are referred to as the *parental generation* or *P generation*. The offspring of that cross are referred to as the *first filial generation* or *F_1 generation*. If members of the F_1 generation are crossed, the offspring resulting from that cross are the *second filial generation* or *F_2 generation*.

Monohybrid Crosses

A *monohybrid cross* is a genetic cross in which the inheritance of one trait is considered. You will now look at two examples of monohybrid crosses.

Example 1: *Rr* × *Rr*

As an introduction to Punnett squares, consider first the genotype of a pea plant that is heterozygous for seed shape, *Rr*. This diploid plant produces two types of gametes in terms of genotypes, *R* and *r*. These two types of gametes are produced in equal numbers; that is, each gamete is as likely to carry an *R* gene as it is to carry an *r* gene. Assume that two parents of this heterozygous genotype are crossed and that you are trying to determine the possible genotypes and phenotypes of the offspring.

The first parent in this example produces *R* and *r* gametes in equal numbers. The same is true of the second parent. Assume that the first parent is ***Rr*** and that the second parent is *Rr*. Therefore, four possible *combinations* of these alleles could be possessed by the offspring: ***R****R*, ***R****r*, *R****r***, and *r****r***. Another way to look at this set of combinations is to use a Punnett square.

In a Punnett square, the gametes of one parent are placed on the top of the square, one gamete above each column. The gametes of the second parent are placed on the left side of the square, one gamete next to each row. Then, within the square, the gametes are combined, illustrating the production of offspring, as shown in Figure 1.2.

Figure 1.2 **Punnett Square 1**

		Parent #1	
		R	***r***
Parent #2	*R*	***R****R*	*R****r***
	r	***R****r*	*r****r***

Parent #1 produces two types of gametes in equal numbers, *R* and *r*. Parent #2 also produces two types of gametes in equal numbers, *R* and *r*. When these gametes combine during fertilization, four possible offspring result. Notice that two of the four offspring have identical genotypes.

The conclusions you can draw from the Punnett square shown in Figure 1.2 include the following:

- There are three possible genotypes in the offspring: *RR*, *Rr*, and *rr*.
- There are two possible phenotypes in the offspring: round and wrinkled.
- The ratio of genotypes in the offspring is 1 *RR* : 2 *Rr* : 1 *rr*.
- The ratio of phenotypes in the offspring is 3 round : 1 wrinkled.

Example 2: *Rr* × *rr*

Assume that two parents with genotypes *Rr* and *rr* are crossed and that you are trying to determine the possible genotypes and phenotypes of the offspring.

The first parent in this example produces *R* and *r* gametes in equal numbers. The second parent can produce only *r* gametes. Therefore, only two possible *combinations* of these alleles could be possessed by the offspring: *Rr* and *rr*. Again, you can use a Punnett square to see this cross more clearly, as shown in Figure 1.3.

Figure 1.3 **Punnett Square 2**

		Parent #1	
		R	*r*
Parent #2	*r*	*Rr*	*rr*
	r	*Rr*	*rr*

The conclusions you can draw from the Punnett square shown in Figure 1.3 include the following:

- There are two possible genotypes in the offspring: *Rr* and *rr*.
- There are two possible phenotypes in the offspring: round and wrinkled.
- The ratio of genotypes in the offspring is 2 *Rr* : 2 *rr*, or more simply, 1 *Rr* : 1 *rr*.
- The ratio of phenotypes in the offspring is 2 round : 2 wrinkled, or more simply, 1 round : 1 wrinkled.

Dihybrid Crosses

It is possible to look at the inheritance of two different traits at one time using Punnett squares. Because two traits are involved in dihybrid crosses, it is necessary to consider Mendel's third law of inheritance, the law of independent assortment. When the genes for two different traits separate into gametes during meiosis, they do so independently of each other. That is, if a parent has the genotype *AaBb*, the law of segregation states that each gamete must have one of the *A* genes (either *A* or *a*) and one of the *B* genes (either *B* or *b*). The law of independent assortment states that each gamete receives these genes independently; that is, the gamete may receive either *A* or *a* and either *B* or *b*. The possible genotypes of the gametes are, as a result, *AB*, *Ab*, *aB*, and *ab*. These four types of gametes are produced in equal numbers during meiosis.

Remember that each parent in a dihybrid cross has genes for both traits. The following example of a dihybrid cross illustrates how gametes combine.

Example: *YyRr* × *YyRr*

In this example, both parents are heterozygous for both traits. Recall that *Y* stands for yellow pods and *y* stands for green pods. The *R* still stands for round seeds and the *r* for wrinkled seeds. These two traits are controlled by the principle of dominance.

Each parent produces four types of gametes: *YR*, *Yr*, *yR*, and *yr*. As a result, the Punnett square that is formed must have 16 squares, as shown in Figure 1.4.

Figure 1.4 **Punnett Square 3**

Parent #2 \ Parent #1	*YR*	*Yr*	*yR*	*yr*
YR	*YYRR*	*YYRr*	*YyRR*	*YyRr*
Yr	*YYRr*	*YYrr*	*YyRr*	*Yyrr*
yR	*YyRR*	*YyRr*	*yyRR*	*yyRr*
yr	*YyRr*	*Yyrr*	*yyRr*	*yyrr*

The conclusions you can draw from the Punnett square shown in Figure 1.4 include the following:

- There are nine possible genotypes in the offspring: *YYRR*, *YYRr*, *YYrr*, *YyRR*, *YyRr*, *Yyrr*, *yyRR*, *yyRr*, and *yyrr*.
- There are four possible phenotypes in the offspring: yellow pods and round seeds, yellow pods and wrinkled seeds, green pods and round seeds, and green pods and wrinkled seeds.
- The ratio of genotypes in the offspring is 1 *YYRR* : 2 *YYRr* : 1 *YYrr* : 2 *YyRR* : 4 *YyRr* : 2 *Yyrr* : 1 *yyRR* : 2 *yyRr* : 1 *yyrr*.
- The ratio of phenotypes in the offspring is 9 yellow pods and round seeds : 3 yellow pods and wrinkled seeds : 3 green pods and round seeds : 1 green pod and wrinkled seed.

Test Crosses

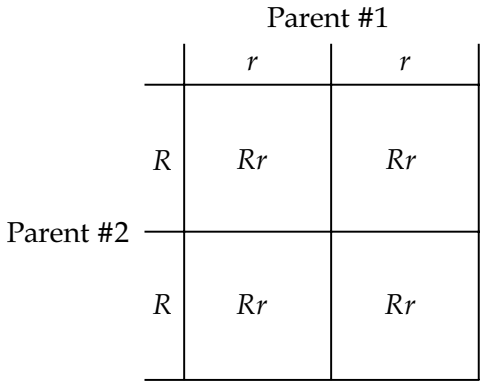
Remember that a pea plant of genotype *RR* is identical in appearance to a pea plant of genotype *Rr* because of the law of dominance. The only method of finding out whether the plant is homozygous or heterozygous is to look at the gametes the plant produces. If the plant is homozygous, it can produce only gametes with the dominant allele. If, on the other hand, the plant is heterozygous, it can produce gametes with either the dominant allele or the recessive allele.

If a plant breeder wanted to breed, in terms of seed shape, a purebred group of round-seeded pea plants, it would be vital to be able to distinguish between *RR* and *Rr* adult plants to use as parents. A test cross would allow the breeder to make that distinction. In a test cross, the organism displaying the dominant phenotype is purposely crossed with an organism displaying the recessive phenotype. If any of the offspring show the recessive phenotype, then the parent displaying the dominant phenotype is heterozygous.

To see this more clearly, consider the two Punnett squares in Figures 1.5 and 1.6.

First possibility: The two parents are *RR* and *rr*.

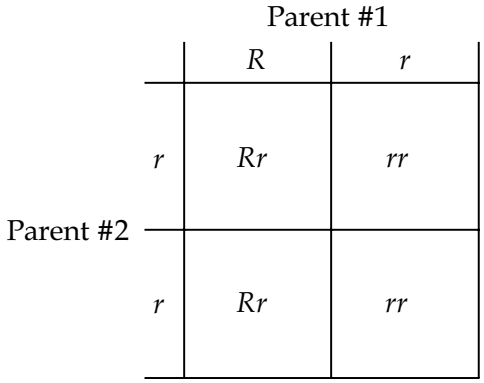
Figure 1.5 **Punnett Square 4**



You can see that none of the offspring displays the recessive phenotype, since none of the offspring is homozygous recessive.

Second possibility: The two parents are *Rr* and *rr*.

Figure 1.6 **Punnett Square 5**



You can see that 50 percent of the offspring display the recessive phenotype. It is clear, then, that the parent displaying the dominant phenotype was definitely heterozygous and not homozygous.

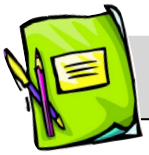
A test cross is used to distinguish, through breeding, a heterozygous parent from a homozygous dominant parent. This is important in many types of selective breeding in which the genotypes of all individuals must be known for a particular trait or set of traits.

Other Inheritance Patterns

You have already learned that Mendel was fortunate that the traits he studied in pea plants were controlled by the law of dominance. For each trait, there was one dominant allele and one recessive allele.

In reality, however, most traits are not controlled by this principle. In fact, there are four special cases of other inheritance patterns that you will consider in this lesson:

- **Co-dominance:** In this pattern of inheritance, two or more alleles are each dominant; each of the alleles results in a phenotype that is shown in the offspring. A good example of co-dominance is human blood type. The allele causing type A blood and the allele causing type B blood are both dominant; when both are present, the individual has type AB blood. Both alleles are able to cover up the allele for type O blood; as a result, the allele for type O blood is recessive to both of the other alleles and is itself recessive.
- **Incomplete dominance:** In this pattern of inheritance, a hybrid organism shows the effects of both alleles; therefore, neither allele is dominant or recessive. The phenotype that results is intermediate between the two purebred phenotypes. A good example is flower colour in snapdragons. An individual that possesses one allele for red flowers and one allele for white flowers displays pink flowers. Both alleles are shown in the offspring.
- **Multiple alleles:** Some traits are controlled by genes that can be present in more than two forms. The trait is said to be controlled by multiple alleles because there are more than two alleles possible. Remember, however, that each diploid organism still possesses only two copies of the gene and that each haploid gamete still possesses only one copy of the gene. The example of human blood type is an illustration of this pattern. There are three, not two, alleles for blood type: type A, type B, and type O. Recall that the type A and the type B alleles are co-dominant over the allele for type O, which is recessive.
- **Lethal genes:** Some lethal traits show up in only the homozygous recessive case. The normal allele is dominant, in other words. As a result, if two parents that are each carriers of the lethal recessive allele produce offspring, roughly 25 percent of their offspring could be homozygous recessive for that trait; those offspring would die, since the lethal characteristic would be expressed.



Learning Activity 1.2: Making Predictions in Genetics

This learning activity will give you an opportunity to review and practise what you have learned about making predictions in genetics. Please record your responses in your notebook.

1. Recall that in pea plants, tall is dominant and short is recessive. Call the two alleles *T* (tall) and *t* (short).
   a) What are the genotypes of the parents if both are homozygous and one is tall while the other is short?
   b) Draw a Punnett square to predict the genotypes of the offspring that these two parents could produce.
   c) What are the possible genotypes of the offspring?
   d) What are the possible phenotypes of the offspring?
   e) The two original parents, *TT* and *tt*, are members of the P generation. What is the name of the generation shown in the Punnett square that you just drew?
   f) Draw a Punnett square illustrating the cross between two members of the F_1 generation.
   g) What are the possible genotypes of the offspring, and in what ratio do they appear?
   h) What are the possible phenotypes of the offspring, and in what ratio do they appear?
   i) To which generation do the offspring shown in the Punnett square belong?

2. Human blood type is controlled by multiple alleles. Two of the three possible alleles are co-dominant and one possible allele is recessive to both the others. The alleles can be called I^A for type A blood, I^B for type B blood, and *i* for type O blood.
   a) What is the genotype of a person with homozygous type A blood?
   b) What is the genotype of a person with homozygous type B blood?
   c) What phenotype would a person with genotype I^AI^B show?
   d) What is the genotype of a person with type O blood?
   e) A man with type A blood and a woman with type B blood have a child with type O blood. How is that possible if the alleles for type A blood and type B blood are both dominant?

(continued)

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 1.2. The assignment details can be found after the Lesson Summary.

Lesson Summary

In Lesson 2 of this module, you expanded your understanding of the study of genetics. You learned how to use Punnett squares to make useful predictions about genetics crosses. You also learned the difference between monohybrid and dihybrid crosses and used Punnett squares to illustrate both. In addition, you learned about patterns of inheritance not predicted by Mendel's study of garden peas. Not all traits are controlled by simple dominance; co-dominance, incomplete dominance, and multiple alleles are all examples of variations seen in nature.

In the next lesson, you will learn about how sex is determined in humans and about some traits that are said to be sex-linked because they occur more often in one sex than in the other. These traits sometimes follow the law of dominance and sometimes they do not.

Assignment 1.2: Making Predictions in Genetics (38 marks)

Please respond to the following assignment questions in the space provided. Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 1.

1. In the case of Dalmatian dogs, the non-spotted condition is recessive to the dominant spotted condition. Call the two alleles *S* for spotted and *s* for non-spotted. Draw a Punnett square to illustrate the cross between two heterozygous parents. Then answer the following questions.
   (6 marks total—2 marks for the Punnett square and 2 marks for each set of questions)

   a) What are the possible genotypes of the offspring? In what ratio do they occur?

   b) What are the possible phenotypes of the offspring? In what ratio do they occur?

(continued)

Assignment 1.2: Making Predictions in Genetics (continued)

2. Consider again the case of Dalmatian dogs. Say that a spotted dog and a non-spotted dog are crossed. Is it possible for them to produce any non-spotted puppies? Why or why not? Explain your answer using Punnett squares. *(4 marks)*

(continued)

Assignment 1.2: Making Predictions in Genetics (continued)

3. In some mice, the allele *P* causes normal coloration and the allele *p* causes a lack of pigment to occur, called *albinism*. Coloration is controlled by simple dominance. Another trait, ear shape, is also controlled by simple dominance; for this trait, the allele *N* causes normal ear shape and the allele *n* causes folded ears. Use a Punnett square to predict the offspring of Parent #1 who is heterozygous for both traits and Parent #2 who is albino but is purebred for normal ear shape. Then answer the following questions. *(10 marks total—2 marks for the Punnett square and 2 marks for each set of questions)*

   a) What are the possible genotypes of the offspring? In what ratios do they occur?

   b) What are the possible phenotypes of the offspring? In what ratios do they occur?

(continued)

Assignment 1.2: Making Predictions in Genetics (continued)

c) Are any offspring produced exactly like Parent #1

- in terms of genotype? How many out of 16?

_____

_____

- in terms of phenotype? How many out of 16?

_____

_____

d) Are any offspring produced exactly like Parent #2

- in terms of genotype? How many out of 16?

_____

_____

- in terms of phenotype? How many out of 16?

_____

_____

(continued)

Assignment 1.2: Making Predictions in Genetics (continued)

4. In some cattle, coat colour is controlled by a gene that has two alleles that are co-dominant: *R* for red coat and *W* for white coat. A heterozygous animal is roan in colour and has a mixture of red and white hair in its coat. Use a Punnett square to show the cross between a red animal and a roan animal. Then answer the following questions. *(6 marks total—2 marks for the Punnett square and 2 marks for each set of questions)*

   a) What are the possible genotypes of the offspring? In what ratios do they occur?

   _____

   _____

   b) What are the possible phenotypes of the offspring? In what ratios do they occur?

   _____

   _____

(continued)

Assignment 1.2: Making Predictions in Genetics (continued)

5. In some varieties of corn, yellow seed colour is a dominant trait, while purple seed colour is a recessive trait. Using a test cross, explain how you would determine the genotype of a plant that possesses yellow seeds. *(4 marks)*

(continued)

Assignment 1.2: Making Predictions in Genetics (continued)

6. In the fruit fly (*Drosophila*) the allele for dumpy wings, *d*, is recessive to the normal allele for long wings, *D*. The allele for ebony body colour, *e*, is recessive to the normal allele for wild (grey) body colour, *E*. In a cross between a purebred, long-winged fly that is heterozygous for body colour and a second fly that is heterozygous for wing shape and body colour, use a Punnett square to show the expected genotypes of their offspring. Then answer the following questions. *(8 marks total—4 marks for the Punnett square and 2 marks for each set of questions)*

   a) What are the possible genotypes of the offspring? In what ratio are they expected to occur?

   b) What are the possible phenotypes of the offspring? In what ratio are they expected to occur?

Notes

Lesson 3: Sex Determination and Sex-Linked Traits

Lesson Focus

In this lesson, you will

- ❑ explain the basis for sex determination in humans
  Include: XX and XY chromosomes
- ❑ describe examples of and solve problems involving sex-linked genes
  Examples: red-green colour-blindness, hemophilia, Duchenne muscular dystrophy . . .

Introduction

So far in this module, you have learned about the fundamental laws of genetics first suggested by Gregor Mendel, and you have used that foundation to build an understanding of how to make predictions about particular genetic crosses, using Punnett squares to illustrate both monohybrid and dihybrid crosses. You have also learned about some notable exceptions to Mendel's laws of genetics, such as the existence of multiple alleles, incomplete dominance, and co-dominance.

In this lesson, you will learn about a particular pair of chromosomes in humans that is responsible for gender determination. In addition, you will learn about a set of human traits that is controlled by genes located on the sex chromosomes; these traits are said to be *sex-linked*.

Sex Determination in Humans

Recall that the normal human diploid chromosome number is 46. That is, each individual possesses 23 pairs of chromosomes, one of each pair coming originally from each of the individual's parents. When two haploid gametes fuse as fertilization occurs, the diploid chromosome number is restored in the zygote.

Of the 23 pairs of chromosomes in human body cells, one pair is special because it determines the gender of the individual. This one pair of chromosomes is referred to as the pair of *sex chromosomes*. Each individual human possesses two of these sex chromosomes in each body cell. Sex chromosomes have two possible shapes; the longer of the two types is referred to as the *X chromosome* and the shorter of the two types is referred to as the *Y chromosome*. In humans, if the individual possesses two X chromosomes, that person is female. If the individual possesses one X and one Y chromosome, that person is male. Two Y chromosomes do not produce a viable embryo.

The other 22 pairs of chromosomes in a diploid human body cell are called *autosomes* because they are not involved in gender determination of the individual.

Now, recall that when a person's body manufactures gametes for reproduction, those gametes possess only one copy of each type of chromosome. So, a woman produces only X egg cells and a man produces some X and some Y sperm cells. It is clear, then, that the genotype of the sperm cell determines the gender of the child. The mother always contributes an X cell, but the father may contribute either an X cell (in which case the offspring would be female) or a Y cell (in which case the offspring would be male). Therefore, an individual's gender is determined at the time of fertilization by the type of sex chromosome present in the sperm that fertilizes the egg.

Through the first six weeks of pregnancy, the embryo develops as a female. Sex differentiation occurs in the seventh week of embryonic development. Genes on the Y chromosome trigger the release of male hormones that stimulate the development of male reproductive organs. If male hormones are not released, the embryo continues to develop as a female in response to the release of female hormones. The male and female reproductive organs are produced from the same embryonic tissues.

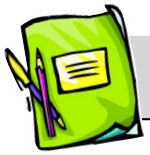
Sex-Linked Traits in Humans

The fact that an X chromosome is longer than a Y chromosome means that an X chromosome actually carries more genes than the Y chromosome carriers. In fact, the Y chromosome carries little genetic information. As a result, there are some genes of which females possess two copies, since they carry two X chromosomes, and males possess only one copy, since they carry one X chromosome and one Y chromosome. This leads to the existence of *sex-linked traits*.

Sex-linked traits are caused by recessive genes located on the sex chromosomes. Call the recessive gene *r* and say that it causes a particular trait. If a female has only one recessive gene, *r*, among her X chromosomes, she will not show the trait as long as the other gene she possesses is dominant, *R*. But if a male has only one recessive gene, *r*, he will show the trait since he does not possess another gene to mask it because he only possesses one X chromosome. This is particularly true in traits that are very obvious or that are detrimental. As a result, men typically show recessive sex-linked traits much more commonly than women do.

To show that women possess two copies of sex-linked genes and men possess only one copy of that gene, different notations are used. If the recessive gene is *r*, a female carrying one copy has the genotype X^RX^r and a male carrying one copy has the genotype X^rY. By using the letters X and Y, it is easier to remember that the case being studied is sex-linked.

There are a number of examples of such recessive sex-linked traits in humans. One good example is *hemophilia*, a blood disorder in which the blood does not adequately clot when an injury occurs. The following symbols are typically used for the two genes involved: X^H (normal) and X^h (hemophilia). Another example of a recessive sex-linked trait is red-green colour-blindness, which occurs much more often in males than it does in females.



Learning Activity 1.3: Sex-Linked Traits

This learning activity will give you an opportunity to review and practise what you have learned about sex-linked traits. Please record your responses in your notebook.

1. A couple has four children, all of whom are boys. What is the chance that their next child will be a girl?

2. Duchenne muscular dystrophy (DMD) is a recessive, sex-linked disorder. A man and a woman who are both free of the disorder have two children. Their elder son develops DMD, while their younger son is free of the disorder. Let the recessive gene be X^m and the dominant gene be X^M.

   a) Determine the genotypes of the parents.

   b) Determine the genotypes of the children.

3. A woman whose father was red-green colour-blind and a man with no history of colour-blindness in his family plan to start a family. What is the chance that they will have children who are colour-blind? Let the recessive gene be X^c and the dominant gene be X^C.

4. Given the following data, determine the inheritance pattern of black, orange, and calico coat colour in cats.

   Hints: male cats are XY and female cats are XX. Calico is a mix of orange and black fur.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 1.3. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about human sex chromosomes and the inheritance patterns seen in traits that are sex-linked. Sex-linked traits are exceptions to Mendel's fundamental laws of inheritance. In the lesson that follows, you will learn about a method used to study how traits are inherited through a number of generations of related individuals. You will also consider ethical issues related to human genetics testing.

Notes

Assignment 1.3: Sex-Linked Traits (44 marks)

Please respond to the following assignment questions in the space provided. Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 1.

1. Recall that red-green colour-blindness is a relatively rare, recessive sex-linked trait in humans. Explain how a man who has red-green colour-blindness rarely fathers a son who also possesses the trait. *(2 marks)*

(continued)

Assignment 1.3: Sex-Linked Traits (continued)

2. Hemophilia is a relatively rare, recessive sex-linked trait in humans. Say that a man with hemophilia marries a woman who is homozygous normal (does not have hemophilia). Let X^H be the normal gene and X^h be the recessive gene. Draw a Punnett square illustrating this cross, and then answer the following questions. *(14 marks total—2 marks for the Punnett square and 2 marks for each question)*

   a) What type or types of gametes can the father produce?

   _____

   b) What type or types of gametes can the mother produce?

   _____

   c) What is the probability that their daughters will be carriers of the gene for hemophilia (but not show the trait themselves)?

   _____

   d) What is the probability that their daughters will have hemophilia?

   _____

   e) What is the probability that their sons will be carriers of the gene for hemophilia (but not show the trait themselves)?

   _____

   f) What is the probability that their sons will have hemophilia?

   _____

(continued)

Assignment 1.3: Sex-Linked Traits (continued)

3. A colour-blind man (X^cY) marries a woman with normal vision whose father is colour-blind. Show the gametes of the man and the woman, and complete a Punnett square to illustrate this cross. Then answer the following questions. *(14 marks total—2 marks for the Punnett square and 2 marks for each question)*

a) What type or types of gametes can the father produce?

_____

b) What type or types of gametes can the mother produce?

_____

c) What is the probability that their daughters will be carriers of the gene for colour-blindness (but not show the trait themselves)?

_____

d) What is the probability that their daughters will be colour-blind?

_____

e) What is the probability that their sons will be carriers of the gene for colour-blindness (but not show the trait themselves)?

_____

f) What is the probability that their sons will be colour-blind?

_____

(continued)

Assignment 1.3: Sex-Linked Traits (continued)

4. A man with hemophilia marries a woman who is a carrier for the gene. Show the gametes of the man and the woman, and complete a Punnett square to illustrate this cross. Then answer the following questions. *(14 marks total—2 marks for the Punnett square and 2 marks for each question)*

a) What type or types of gametes can the father produce?

_____

b) What type or types of gametes can the mother produce?

_____

c) What is the probability that their daughters will be carriers of the gene for hemophilia (but not show the trait themselves)?

_____

d) What is the probability that their daughters will have hemophilia?

_____

e) What is the probability that their sons will be carriers of the gene for hemophilia (but not show the trait themselves)?

_____

f) What is the probability that their sons will have hemophilia?

_____

Lesson 4: Inheritance Patterns and the Ethics of Predicting Genetics

Lesson Focus

In this lesson, you will

- ❑ use pedigree charts to illustrate the inheritance of genetically determined traits in a family tree and to determine the probability of certain offspring having particular traits

  Include: symbols and notation used

- ❑ discuss ethical issues that may arise as a result of genetic testing for inherited conditions or disorders

Introduction

In the first three lessons of this module you learned about Mendel's basic laws of inheritance and about how Punnett squares can be used to understand how traits are passed from one generation to the next. You also learned about sex-linked traits that are exceptions to the basic laws of dominance and independent assortment. It is possible, and sometimes important, to be able to trace the inheritance of a trait through several generations; such a study allows for an understanding of how a trait is determined and where the gene or genes controlling it are located. In this endeavour, *pedigree charts* are commonly used to show how a trait is passed on through a number of generations of the same family.

In the second half of this lesson, you will consider the ethics surrounding genetic research aimed at identifying genetic abnormalities. Genetic counsellors use several methods to advise parents of potential risks.

Pedigree Charts

Pedigree charts can be created to show how a particular trait is inherited through a number of generations in a given family. By convention, the following symbols are usually used in the creation of a pedigree chart:

- ☐ Male individual who does not possess the trait being considered.
- ■ Male individual who does possess the trait being considered.
- ○ Female individual who does not possess the trait being considered.
- ● Female individual who does possess the trait being considered.
- — Marriage linking the parents.

  Children of a couple are represented along a horizontal line beneath the line connecting their parents.

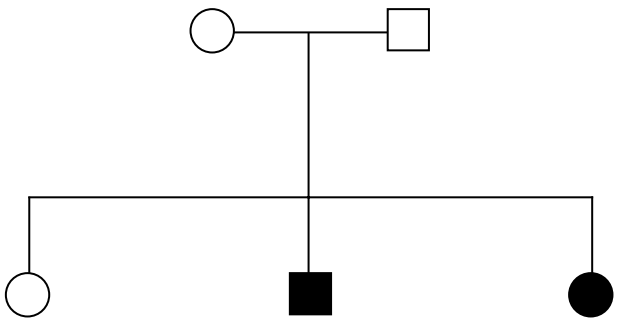
  The parental generation is joined to the first filial generation by a vertical line.

Sometimes, when looking at a pedigree chart, you will know the type of gene that controls the inheritance of the trait in question. For example, you may know that it is a dominant allele, or you may know that it is a recessive, sex-linked allele. On the other hand, sometimes you do not know the type of gene involved and you may have to determine that by analyzing the pedigree chart. Pedigree charts show only phenotype and gender; this leaves genotypes to be determined logically.

It is important to note that recessive traits are not always rare traits and dominant traits are not always common traits. Also, if two parents who do not possess a trait produce an offspring that does possess the trait, then the gene involved *must be recessive*, and both parents must be heterozygous.

Consider the example shown in Figure 1.7.

Figure 1.7 **Pedigree Chart 1**

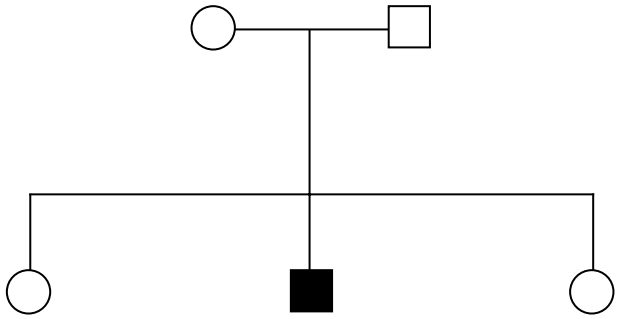


In this example, the pedigree chart is shown for two generations. Neither of the parents possesses the trait, nor does their first child, a daughter. However, both their second child and their third child show the trait. In this example, the trait is caused by a recessive gene that is autosomal and not sex-linked. Both the parents must be heterozygous for the trait. Their first child may be either homozygous dominant or heterozygous since both genotypes result in the same phenotype. Both the second child and the third child must be homozygous recessive. If the recessive allele is *b* and the dominant allele is *B*, the parents are both *Bb*, the first daughter is either *BB* or *Bb*, and both the remaining children are *bb*.

Now look at a trait that is caused by a recessive sex-linked trait. Recall that a recessive sex-linked trait appears far more often in males than it does in females, because males possess only one copy of the gene, which is located on the X chromosome. If a female possesses only one copy of the recessive gene, she will not show the trait, because her other allele will be dominant.

Consider the example shown in Figure 1.8.

Figure 1.8 **Pedigree Chart 2**



Notice that this pedigree chart is similar to the first example; however, here you are considering the inheritance of a recessive sex-linked trait. Assume that the recessive sex-linked allele is X^b and that the normal dominant allele is X^B. Recall that the Y chromosome does not carry genes for sex-linked traits. The son of this cross does show the trait, so his mother must possess at least one recessive allele, since the son received his Y chromosome from his father. You know that the father is X^BY, since he does not show the trait. The son is X^bY, so he received that X^b from his mother. The mother must also possess a dominant gene, X^B, since she does not show the trait. So, the mother has a genotype X^BX^b, the father is X^BY, both daughters are either X^BX^B or X^BX^b, and the son is X^bY.

In some pedigree charts, heterozygous individuals are shown as either a circle or a square that has a vertical line through it, separating a clear side and a solid side. If the trait is autosomal, both squares and circles can be divided in that manner. If, on the other hand, the trait is sex-linked, only circles can be divided, since males possess only one gene for the trait. In Learning Activity 1.4: Human Pedigree Charts, found later in this lesson, you will consider an example that uses this method. Specifically, you will learn about the inheritance of hemophilia in the descendants of Queen Victoria in the royal families of Europe.

Recall that *hemophilia* is a disease characterized by the individual's body being unable to form blood clots properly. In the past, hemophilia was untreatable; as a result, those who had hemophilia rarely survived to have children of their own because even a small injury could be fatal. Because hemophilia was so common in Queen Victoria's descendants, it became known as the *royal disease*. Because her descendants married into other royal families of Europe, the disease appeared in Spain, Russia, and Prussia, as well as in England.

Genetic Testing

Research in the broad field of genetics has continued to grow for the last several decades in a number of countries around the world. Of particular interest here is the growing knowledge of the human genetic code and human genetic testing.

Genetic research is resulting in rapidly increasing amounts of genetic knowledge. However, not all genetic disorders and diseases are fully understood. Knowledge gained through research is not always passed on effectively to health care professionals or to patients. Furthermore, many genetic procedures are very costly or are available in only specific locations. Many patients of genetic disorders and diseases do not know whether their conditions could have been prevented, could have been detected or treated earlier, or could be passed on to some or all of their children.

As result of some of these difficulties in bridging the gap between research and patient care, the role of genetic counselling has emerged and continues to evolve. Genetic counselling is conducted by health care professionals who are trained to assist families in understanding genetic disorders and diseases. They provide information and support to patients and their families. At times, genetic counsellors may serve as patient advocates when they refer patients to medical services that could be helpful.

A number of genetic-testing technologies have been developed in order to identify genes causing genetic disorders and diseases. One type of genetic testing is done during pregnancy to study the genes present in the developing fetus.

Types of Prenatal Genetic Screening and Testing

Genetic counsellors are able to help parents with information gained through prenatal screening and testing procedures. Screening techniques sometimes involve a blood test for the mother; the presence or absence of some proteins may indicate that further genetic testing, such as ultrasound or amniocentesis, is needed to confirm a diagnosis. Blood testing is routine during pregnancy.

The various types of prenatal genetic screening and testing include the following:

- **Maternal serum alpha-fetoprotein (MSAFP) screen:** This screening is made available to women when they have regular blood tests done during pregnancy. These tests screen for the presence of specific blood proteins that indicate neural tube abnormalities, such as spina bifida, and other genetic disorders, such as Down syndrome. This blood work is usually done between the 11th and 14th weeks of pregnancy. False positives are possible, so other testing may be needed.
- **Quad marker screen:** This screening technique tests maternal blood between the 15th and 20th weeks of pregnancy for four substances that normally originate in the fetus's brain, blood, and spinal fluid, and in the amniotic fluid. This test is done if the MSAFP screening has not already been done. It also has a false positive rate of about 1 in 20 patients, so further testing is required if positive results occur. This technique screens for possible developmental or chromosomal disorders.
- **Ultrasound:** This screening technique is usually done between the 18th and 20th weeks of pregnancy. Sound waves are produced from a transducer that is moved over the pregnant woman's abdomen. Images produced on a screen allow for an assessment of the growth and development of the fetus. This technique can also identify various congenital abnormalities, some of which may be treatable before birth.
- **Amniocentesis:** This diagnostic test involves using an ultrasound-guided needle inserted into the pregnant woman's abdomen to remove a small amount of amniotic fluid. This test is done after the 15th week of pregnancy, and more safely after the 24th week of pregnancy. This test is generally done after a screening tool has produced results that fall outside the normal range. Amniocentesis can detect some chromosomal abnormalities and certain genetic problems such as Down syndrome and spina bifida. When performed before the 24th week, an average of 1 in 200 pregnancies ends in miscarriage after this procedure.

- **Chorionic villus sampling (CVS):** This test involves taking a sample of the placenta between the 9th and 14th weeks of pregnancy. Two methods of acquiring the sample are used. The first involves inserting a needle into the uterus, using ultrasound as a guide. The second involves threading a tube through the cervix in order to remove the sample. About 1 in 100 pregnancies ends in miscarriage after this procedure.
- **Percutaneous umbilical blood sampling (PUBS):** This technique involves testing a sample of the fetus's blood to look for disorders, such as sickle-cell anemia, hemophilia, anemia, Rh disease, and a number of other conditions. With this technique, a blood sample is taken from the vein in the umbilical cord after the 18th week of pregnancy. Ultrasound helps locate the vein, while a needle is inserted into the pregnant woman's abdomen. About 1 in 50 pregnancies ends in miscarriage after this procedure.

The Ethics of Prenatal Genetic Screening and Testing

Blood tests and ultrasounds are both routinely used during pregnancy to screen for common conditions. Screening tests pose no risk to either the pregnant woman or to the fetus. More invasive diagnostic testing, however, does involve risk and should, therefore, be carefully considered before being conducted. After abnormal screening results appear, diagnostic tests may be conducted for women beyond a certain age or for members of a family whose history puts them at an increased risk of a particular genetic problem.

Normal results ease the anxiety of concerned parents; however, if the testing shows that the child may have a birth defect, difficult choices may be required. Knowing that a child may or will be born with a disorder or a disease allows parents and physicians to plan for the baby's care in advance of the birth. For some couples, abnormal results may mean deciding to terminate the pregnancy. Some prenatal tests detect problems that can be treated before birth. They can also detect problems that require immediate treatment after birth.

A genetic counsellor can provide information and support for parents trying to decide whether or not to choose prenatal diagnostic testing. It is important to remember that prenatal diagnostic testing procedures are always optional. Furthermore, positive results do not necessarily mean that the abnormality exists, and negative results do not erase all risk of abnormality; genetic testing is not 100 percent accurate.

Genetic Testing after Birth

Although never required, it is possible for individuals to seek genetic testing for themselves. Sometimes genetic testing is done because an individual's family history indicates the possibility that he or she may carry a particular gene. This is of particular interest if that individual is considering having children and possibly passing that gene on to them.

Keep in mind that there are a limited number of genetic abnormalities, disorders, and diseases whose genes can be identified using genetic testing tools. Also, not all abnormalities, disorders, and diseases are genetic in nature. Genetic testing tools are useful in identifying the possible presence of genes shown to be linked to a limited number of abnormalities, disorders, and diseases. Currently, there are about 1000 genetic abnormalities that can be identified in humans using DNA testing. These include breast and ovarian cancer, cystic fibrosis, sickle-cell anemia, hemophilia, Huntington disease, phenylketonuria, and Duchenne muscular dystrophy.

Testing may simply require a blood sample to be taken from the patient; alternatively, a swab sample from the inside of the patient's cheek may be needed. In rare cases, a skin or muscle biopsy may be required. Other testing or diagnostic procedures may be required to confirm results found through genetic testing.

The cost of genetic testing varies greatly and depends on a number of factors. Medical coverage varies considerably. Genetic counsellors can provide information about both availability and affordability of genetic testing procedures.

An example of a relatively new genetic testing tool is one that investigates hereditary susceptibility for breast and ovarian cancer. Two breast cancer genes have been shown, when abnormal, to indicate increased cancer susceptibility. These genes have been called BRCA-1 and BRCA-2. Changes in both genes are linked to an increased susceptibility for developing breast, ovarian, and other forms of cancer. Not all breast cancer cases involve a hereditary form of cancer, but of those that do, a relatively high percentage of cases involve mutations of either or both of these two genes.

Abnormal forms of these two genes, BRCA-1 and BRCA-2, can be inherited from either the mother or the father. When a person is identified with breast or ovarian cancer, genetic testing may be done to look for mutations in these two genes. If a mutation is found, then the cancer has a genetic component, and other family members may be alerted to the possibility of possessing the gene. If a mutation is not found, the cancer would not appear to have a genetic component. A mutation in either of these genes does not mean that the person involved will necessarily have or get cancer. It is suspected that a number of

non-genetic factors may influence the risks associated with these mutations if they have been identified.

If a person does receive a positive result for having a mutation in either the BRCA-1 or the BRCA-2 gene, he or she may consult with a physician about increasing monitoring procedures such as mammograms. As in previous examples, genetic counselling can provide information and support prior to and following genetic testing of this type.

A number of disorders and diseases have been shown to have a genetic component; some of these illnesses have been linked to a specific gene or a set of genes known to exist at a particular location on a particular human chromosome. Like breast and ovarian cancer, cystic fibrosis has been found to have a genetic component. *Cystic fibrosis* is a lifelong illness usually diagnosed during the first few years of life. It affects the respiratory and digestive systems in particular. There is no cure for cystic fibrosis, and it does shorten the patient's life span. Patients suffering from this disease vary greatly in terms of how much the disease affects them and their lives; although prenatal screening can identify the gene for cystic fibrosis, the severity of the symptoms cannot be predicted. Since the gene that causes cystic fibrosis is recessive and rare, a person who is heterozygous does not have the disease or show any symptoms of carrying the gene. But if two people who are both carriers have children together, their child has a 25 percent chance of being born with cystic fibrosis. Fortunately, the genetic screening tool that is available now for cystic fibrosis identifies carriers, even though they are identical to homozygous normal individuals in phenotype.

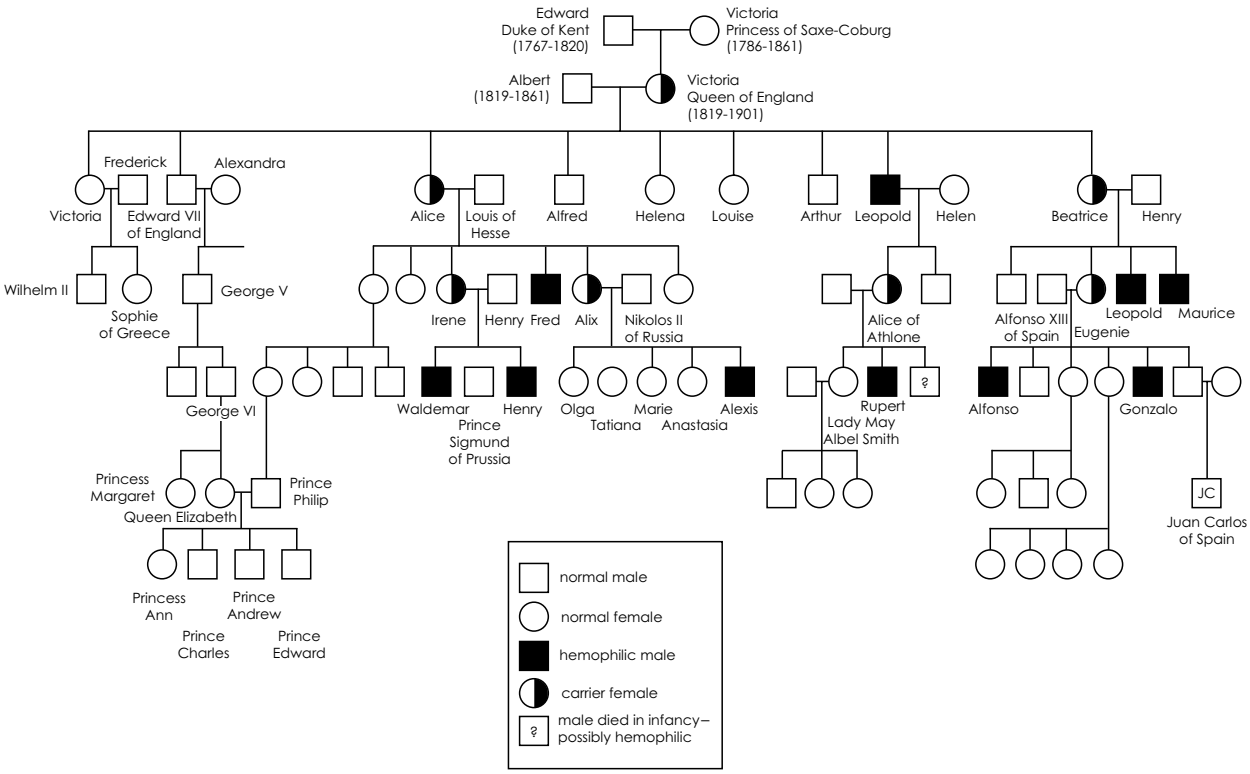
Some pre-symptomatic genetic tests are conducted on patients whose family history indicates that they seem likely to suffer from the disease in question. For example, a pre-symptomatic genetic test has been developed for Alzheimer disease, but its use is controversial. Such tests indicate only the probability that the person will get the disease. But not everyone who is genetically predisposed to get Alzheimer actually does get the disease.

With scientific knowledge and understanding of the human genome increasing at such a great rate, an ever-growing number of genetic disorders and diseases will be identified by the genes linked to their occurrence. This will allow the identification and treatment of these illnesses to become more effective; it may make prevention of some illnesses a possibility.

Learning Activity 1.4: Human Pedigree Charts

In this learning activity, you will consider the pedigree chart entitled Pedigree of Queen Victoria and Her Descendants (Figure 1.9). Use this chart to answer the questions that follow. Record your responses in your notebook.

Figure 1.9 **Pedigree of Queen Victoria and Her Descendants**



Source: Aronova-Tiuntseva, Yelena, and Clyde Freeman Herreid. "Hemophilia: 'The Royal Disease.'" 20 Sept. 2003. *Case Collection*. www.sciencecases.org/hemo/hemo.pdf. Copyright held by National Center for Case Study Teaching in Science, University at Buffalo, State University of New York, all rights reserved. Reproduced with permission.

In this context, the term *normal* refers to an individual who has the clotting mechanism in the blood, whereas someone with hemophilia does not have this clotting mechanism.

1. How many daughters did Queen Victoria and her husband, Albert, have? How many sons? Did any of their children have hemophilia? If so, what were their names?

(continued)

Learning Activity 1.4: Human Pedigree Charts (continued)

2. If neither Queen Victoria nor Albert had hemophilia, how could any of their descendants have the disease?
3. Consider Leopold and his wife, Helen. Leopold died at the age of 31 after a minor fall. He had suffered repeatedly from severe hemorrhages during his life and was always under careful watch to reduce the chance of injury. Leopold and Helen had one daughter, Alice of Athlone, and one son. Alice of Athlone was a carrier for the recessive gene and her husband was normal. They had three children, a daughter and two sons. One son, Rupert, had hemophilia. The other son and the daughter were of unknown genotype. What is the probability that their other son had hemophilia? What is the probability that their daughter had hemophilia? What is the probability that their daughter was a carrier, like her mother?
4. Since the present royal family is descended from Edward VII of England, explain why hemophilia is not seen in those descendants.
5. Now consider Victoria's youngest daughter, Beatrice, who married Henry and had four children, one normal daughter, one normal son, and two sons with hemophilia. The daughter, Eugenie, married Alfonso XIII of Spain and had six children—two normal daughters, two normal sons, and two sons with hemophilia. Are you surprised by the pedigree that indicates that neither daughter had children with hemophilia? Explain.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 1.4. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about pedigree charts and how they can be used effectively to trace the inheritance of a trait through multiple generations. You have seen how the pattern of inheritance can be used to determine whether the gene is autosomal or sex-linked, dominant or recessive. In particular, you studied the sex-linked recessive gene that causes hemophilia. You also considered some of the ethical questions that surround genetic testing. You learned that genetic counsellors can provide useful information and support to patients dealing with a genetic disorder or disease.

In the next lesson, you will learn about mutations, which are changes in the genetic code. Specifically, you will learn about what happens when mutations occur and how they change the genetic information carried by the cell. Most mutations are harmful and some are lethal. You will also study some genetic abnormalities in humans that are caused by mutations.

Notes

Assignment 1.4: Pedigree Charts and Genetic Testing (39 marks)

Please respond to the following assignment questions in the space provided. Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 1.

1. Consider the pedigree chart (provided in Learning Activity 1.4) showing the inheritance of hemophilia in the family and descendants of Queen Victoria. Queen Victoria's third child, Alice, passed hemophilia on to the German and Russian imperial families. *(9 marks total)*

   - Alice had six children, one of whom had hemophilia. Her only son, Fred, died at the age of three after a fall. Of her five daughters, two were carriers of the recessive gene.
   - One of those heterozygous daughters, Alix, married Tsar Nikolas II of Russia. The recessive gene was thereby introduced into the Russian imperial family.
   - Alix and Nikolas had five children: Olga, Tatiana, Marie, Anastasia, and Alexis. Alexis, their only son, was often in severe pain as a child because of the bleeding into the joints that occurred. But Alexis did not die from hemophilia. At the age of 14, he was executed along with his four older sisters and his parents. None of his sisters had any children, so their genotypes are not known.

   a) What is the probability that Anastasia was heterozygous for the hemophilia gene? What is the probability that she was homozygous recessive? What is the probability that she was homozygous dominant? *(3 marks)*

(continued)

Assignment 1.4: Pedigree Charts and Genetic Testing (continued)

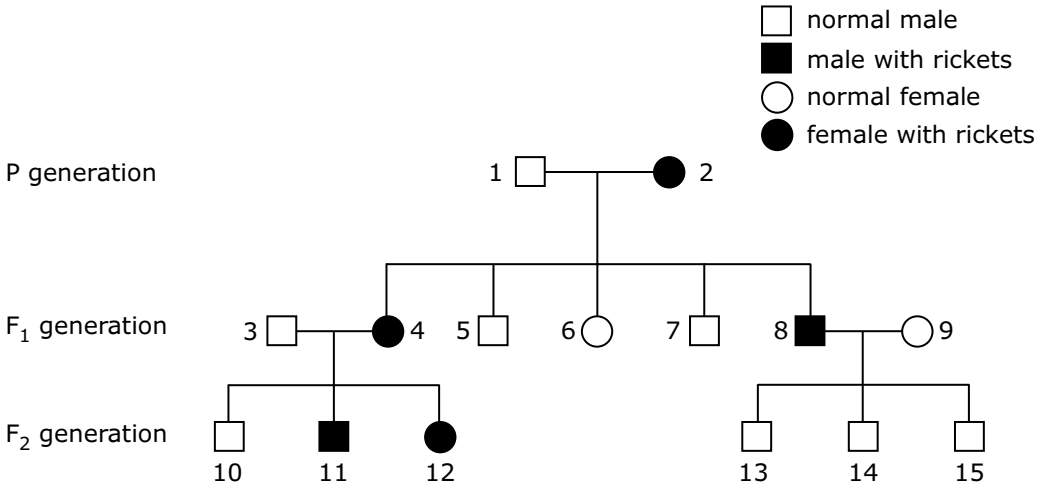
b) If Alexis had lived and had married and had children with a normal, purebred woman, what are the chances that his daughter would have hemophilia? What are the chances that his son would have hemophilia? *(2 marks)*

c) In 1995 a man by the name of Eugene Romanov claimed that he was a grandson of Nikolas II's youngest daughter, Anastasia, whose body had never been recovered. He claimed to share both the last name, Romanov, and the disease of hemophilia with the royal family's lineage. He claimed that Anastasia was not executed but was raised by a farmer and later married and gave birth to a daughter, his mother. Assuming that Eugene's argument was true, what were the likely genotypes of his mother and grandmother if neither had hemophilia? What were the likely genotypes of his father and grandfather if neither had the disease? Could Eugene's argument be true? Why or why not? *(4 marks)*

(continued)

2. The condition known as rickets in humans causes bones in its victims to be abnormally soft. Rickets in children can cause bone deformities. Usually, rickets is caused by a dietary lack of vitamin D, calcium, and phosphorus; rickets is, therefore, not usually a genetic condition. However, one form known as vitamin D-resistant rickets is caused by a dominant allele located on the X chromosome. The pedigree chart in Figure 1.10 shows the inheritance of the genetic form of rickets through three generations of a family. *(20 marks total)*

Figure 1.10 **Pedigree Chart: Inheritance of Genetic Form of Rickets**



a) What is the genotype of the parental female (#2) if *R* is the dominant rickets allele on the X chromosome? Explain your reasoning. *(4 marks)*

(continued)

Assignment 1.4: Pedigree Charts and Genetic Testing (continued)

b) What is the genotype of the parental male (#1)? Explain your reasoning. *(4 marks)*

c) Explain why individual #8 has rickets, but has three sons who do not have rickets. *(4 marks)*

d) What is the genotype of individual #4? Explain your reasoning. *(4 marks)*

e) Individual #10 wonders why he does not have rickets, but his brother and sister both have the disease. Explain how this situation is possible. *(4 marks)*

(continued)

Assignment 1.4: Pedigree Charts and Genetic Testing (continued)

3. Larry and his older brother, Harry, have just found out that their father has been diagnosed with Huntington disease. Larry is 22 years old and Harry is three years older than Larry. *Huntington disease* is an incurable disorder that causes a slow progressive deterioration of the brain, resulting in death. Symptoms appear in the affected individual between the ages of 30 and 50 and they do not improve. Huntington disease is an autosomal dominant disorder for which a genetic screening test has been developed. That test can reveal with 100 percent certainty whether or not the person will develop the disease. Larry is still single, but Harry is married and he and his wife are expecting their first child. In your opinion, should Larry have the screening test for Huntington disease? Why or why not? Should Harry have the test done? Why or why not? *(5 marks)*

(continued)

Assignment 1.4: Pedigree Charts and Genetic Testing (continued)

4. Cynthia is 42 years old and is pregnant with her third child. Routine genetic screening conducted 18 weeks into the pregnancy showed an abnormal result that may indicate that the baby has Down syndrome. Cynthia is being encouraged to consider amniocentesis, which could either confirm Down syndrome or yield normal results. Amniocentesis is not required. In your opinion, should Cynthia proceed with amniocentesis? Why or why not? If she does agree to amniocentesis and the results indicate that the fetus does have Down syndrome, what should Cynthia do? Why? *(5 marks)*

Lesson 5: Genetic Mutations

Lesson Focus

In this lesson, you will

- ❑ discuss the role of meiosis and sexual reproduction in producing genetic variability in offspring
  Include: crossing over and randomness
- ❑ explain how chromosome mutations may arise during meiosis
  Include: nondisjunction
- ❑ identify monosomy and trisomy chromosome mutations from karyotypes
  Examples: Down syndrome, Turner syndrome, Klinefelter syndrome . . .

Introduction

So far in this module, you have studied the basic laws of genetics, the use of Punnett squares in predicting the results of genetic crosses, the use of pedigree charts to study the inheritance of a trait within a family, and the ethics of genetic screening and testing.

In this lesson, you will learn about genetic mutations. *Mutations* are changes in the genetic information of a living cell. There are several types and causes of mutations. Mutations vary in terms of their effects on the cell or organism possessing them; some mutations have little or no effect, and others are lethal. When mutations occur in reproductive cells (gametes), they are passed on to future generations.

Inheritance of Genetic Information

Before learning about genetic mutations, you will review some ideas about how genetic information is inherited in humans. In particular, you will review how genetic information is passed on to offspring through the reproductive cells of the parents.

The diploid chromosome number for humans is 46. This means that somatic cells in the human body possess 23 homologous pairs of chromosomes. One chromosome of each pair came from that person's father and the other chromosome came from that person's mother. When fertilization occurred, the diploid chromosome number of 46 was restored in the first cell of the child. Half of its genetic information came from each parent. One of the chromosomes in each pair of homologous chromosomes came from each parent.

The process that changes one diploid cell into haploid reproductive cells is the process of *meiosis*. It occurs only in the ovaries of women and in the testes of men. Meiosis halves the chromosome number from 46 to 23 in order to create haploid gametes that can fuse and, thereby, restore the diploid chromosome number. You will now look at how mistakes can be made in the process of meiosis as gametes are being formed.

Nondisjunction

When a cell in the ovary or testis is undergoing meiosis, its chromosomes line up on the equator of the cell so that homologous pairs are located next to each other. At that point, each chromosome has replicated itself and, therefore, looks like an X. Each homologous pair looks like two Xs next to each other—or like four single strands united at the centre. This structure is called a *tetrad*. When cell division occurs, one member of each homologous pair migrates to each pole. That is, the two chromosomes in a homologue separate or segregate to opposite sides of the cell during meiosis. At this point, what appeared to be four strands on the equator of the cell become two separate pairs of chromosomes, each pair moving to opposite sides of the cell. Each pair looks like an X, since it is made of two identical chromatids joined at the centromere.

This process, however, does not always proceed perfectly. Sometimes, chromosomal mistakes or mutations occur. One example of such an error is *nondisjunction*. (You will learn about other types of mutations in the next module of this course.) When nondisjunction occurs, an entire tetrad fails to separate into two Xs; instead, it stays together and moves to one end of the cell. As a result, one of the daughter cells receives one extra chromosome and the other daughter cell has one fewer chromosome than the normal haploid number. Some of the gametes carry 24 chromosomes and others carry 22. Both types of gametes are abnormal.

When a gamete (egg or sperm) containing 24 chromosomes joins with a normal gamete in fertilization, the resulting embryo has 47 instead of 46 chromosomes. Similarly, when a gamete containing 22 chromosomes joins with a normal gamete in fertilization, the resulting embryo has 45 chromosomes instead of 46 chromosomes. These are both examples of chromosomal mutations.

The genetic conditions that result from this nondisjunction of homologous pairs of chromosomes during meiosis vary widely in their effects on the individual.

Autosomal Nondisjunction

Recall that autosomes are the 44 chromosomes (22 pairs) in a human cell that are not sex chromosomes (X and Y). When nondisjunction occurs during the formation of egg or sperm and it happens to any of the autosomal pairs, it is usually a lethal mutation. That is, a human cell that has 45 or 47 chromosomes because of either an extra autosome or a missing autosome usually does not survive. In part, this is due to the great number of genes located on each autosome.

There is, however, a notable exception to this generalization. When an extra member of chromosome pair number 21 occurs in the embryo, that embryo survives. The condition is called *Down syndrome* or *trisomy 21*, which means that it is due to three copies of chromosome 21. Nondisjunction occurred in the formation of gametes and an abnormal chromosome number of 47 results in the embryo. Down syndrome has various characteristics, including intellectual disability. At the present time, about 1 in every 800 children in Canada has Down syndrome. It is noteworthy that this autosomal trisomy is not lethal. Autosomal monosomies are lethal because the individual is missing one entire chromosome. The information carried on it is not available to the embryonic cell. Not all mutations are compatible with life.

Nondisjunction of the Sex Chromosomes

Recall that sex chromosomes are the two chromosomes (one pair) in a human cell that are either XX in females or XY in males. The Y chromosome is remarkably smaller than the X chromosome and does not carry as many genes. The sex chromosomes are subject to meiotic nondisjunction, just like the autosomes.

If nondisjunction occurs during the meiotic divisions that produce an egg cell, two kinds of cells will result. One egg will contain both of the X chromosomes and the other will have no X chromosome. If these abnormal egg cells each fused with a normal sperm cell, the sex chromosomes in the resulting zygote would possess one of the following genotypes:

XXX: This genotype is a trisomy and is referred to as *triplo-X*. The egg cell contributed two X chromosomes and the sperm cell contributed one X chromosome. An individual with this genotype is female and has no physical abnormalities, but has intellectual disability. A female with this genotype is usually fertile. The children of XXX women are usually normal; during egg production, the additional X chromosome is somehow discarded in the gametes that form.

XXY: This genotype is a trisomy and is referred to as *Klinefelter syndrome*. The egg cell contributed two X chromosomes and the sperm cell contributed one Y chromosome. An individual with this genotype is male in terms of general appearance. However, the presence of the extra X chromosome prevents the normal development of the testes. Therefore, most XXY males are sterile. They also have enlarged breasts, very little body hair, and longer than usual arms and legs. Many XXY males have some degree of deficits in intellectual functions.

XO: This genotype is a monosomy and is referred to as *Turner syndrome*. The egg cell contributed no sex chromosome and the sperm cell contributed one X chromosome. This individual is female, is short in stature, has some webbing of the skin of the neck, and has some degree of mental impairment. The ovaries, if they are present in these individuals, are very underdeveloped. As a result, the development of secondary sex characteristics such as breast enlargement and body hair is severely inhibited. These individuals are sterile. This mutation is not always compatible with life; roughly 1 of every 10 spontaneous miscarriages has the XO genotype.

YO: This is a monosomy that has never been found to occur. Apparently, an egg cell that has no sex chromosomes cannot be successfully fertilized by a sperm cell containing a Y chromosome. This is probably due to the fact that the X chromosome contains far more genes than the Y chromosome does; a cell that does not contain at least one X chromosome cannot survive.

Another occurrence results when a normal male zygote that possesses XY chromosomes divides after fertilization by mitosis. The zygote with genotype XY should produce two daughter cells that also have the XY genotype. These two cells then each produce two daughter cells, and so on, as the zygote develops, through cell division, into the embryo. If an error occurs

during one of these very early cell divisions, a different type of trisomy can occur—XYY. The other cell produced from that cell division would only contain the remaining X chromosome. If the XYY cell survives and the X cell does not, all subsequent daughter cells will have the genotype XYY. Most often, the presence of an extra Y chromosome causes no medical problems and no unusual physical features. Generally, sexual development is normal and these individuals are fertile.

Since the XYY condition is not characterized by a particular phenotypic trait, it is usually detected only when genetic analysis is done for another reason. Some studies link learning difficulties and lower intelligence quotient (IQ) scores to the XYY genotype. Others show an increased occurrence of developmental delays and behavioural problems in XYY individuals; however, these results vary greatly and are not always present. It has been estimated that about 1 in 1000 boys is born with the XYY genotype.

XYY can also result because of nondisjunction in the formation of sperm cells in the male. As a result of such a nondisjunction, some sperm would contain two Y chromosomes and other sperm would contain no sex chromosomes.

Karyotype Analysis

You may be wondering how it is possible to know whether an individual has any of the chromosomal abnormalities that result from nondisjunction. To make such a determination, a *karyotype* must be prepared, using a sample of that individual's body cells. If the individual is an adult, white blood cells are used. If the individual is a developing fetus, cells from the amniotic fluid are used. These sample cells are placed in a solution that has the same salinity as blood. The temperature is maintained at roughly normal human body temperature. The culture solution also contains *phytohemagglutinin*, a substance that stimulates white blood cell division. The cells are allowed to divide and grow in this solution.

Chromosomes are most easily seen during the phase of mitosis called *metaphase*. During this phase, the chromosomes are thick and short and are aligned on the cell equator. It would be convenient if one could somehow stop the mitotic division at this stage in order to see and count the chromosomes. A chemical called *colchicine* stops cell division; it causes the cells to "freeze" where they are in the mitotic process. Different cells will stop in different stages of mitosis. Some of them will stop during metaphase. These are the cells that will allow the analysis of chromosomes.

At this point, the solution is placed in a centrifuge, a machine that spins small containers of liquid very rapidly. This causes the cells to move to the bottom of the tube, since they are denser than the rest of the solution. After spinning, the culture liquid is removed and is replaced by a *hypotonic* solution; it causes the cells in the tube to swell so that the chromosomes are spread out over a larger area of the cell. At this point, a fixative is added, which prevents the cells from any further swelling or shrinking. A slide is prepared of the cells, and they are stained for easier visibility. The slide is analyzed and particular cells are photographed. The photograph is enlarged to make the chromosomes large enough to identify, and then it is cut up so that each chromosome is a separate X. The chromosomes are then counted and identified by shape and size. The resulting picture or visual display of the set of chromosomes is called a *karyotype*, which can be used to identify specific chromosomal mutations, such as the monosomies and trisomies that you have learned about in this lesson.

Figure 1.11 shows a normal male karyotype. Note that 22 pairs of autosomes and one pair of sex chromosomes, XY, are present.

Figure 1.11 **Normal Male Karyotype**

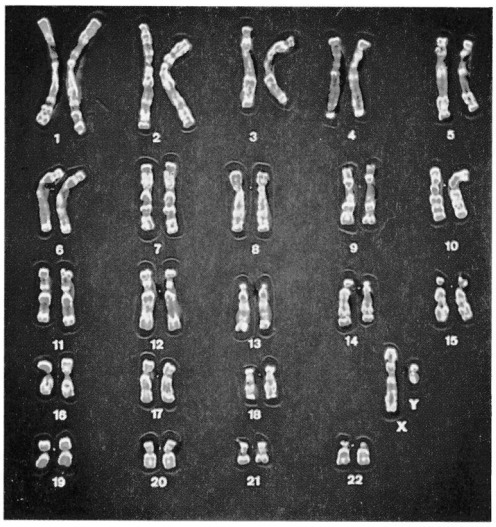


Photo credit: © CNRI/SPL/Photo Researchers, Inc.

Source: Mader, Sylvia S. *Inquiry into Life*. 11th ed. New York, NY: McGraw-Hill, Higher Education, 2006. 523.

Figure 1.12 shows a karyotype of a male with the XYY genotype. Two Y chromosomes and one X chromosome are present.

Figure 1.12 **Male Karyotype with XYY Genotype**

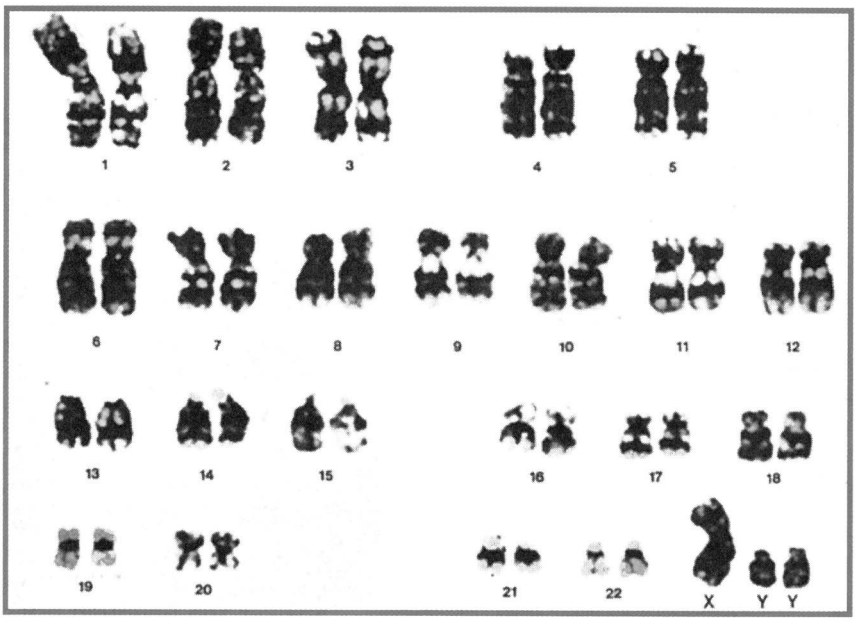


Photo credit: Biophoto Associates/Photo Researchers

Source: Biggs, Alton, et al. *Glencoe Science Biology: The Dynamics of Life*. Columbus, OH: Glencoe/McGraw-Hill, 2004. 329.

In Figures 1.13 and 1.14, consider the karyotypes and the chromosomal mutations that they illustrate.

Figure 1.13 **Turner Syndrome**

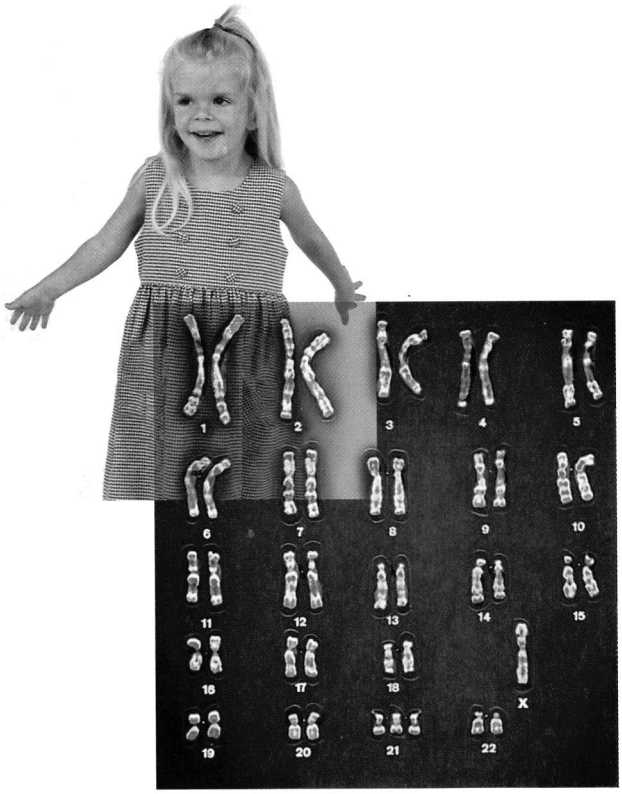


Photo credit: © CNRI/SPL/Photo Researchers, Inc.; UNC Medical Illustration and Photography

Source: Mader, Sylvia S. *Inquiry into Life.* 11th ed. New York, NY: McGraw-Hill, Higher Education, 2006. 526.

Figure 1.14 **Klinefelter Syndrome**

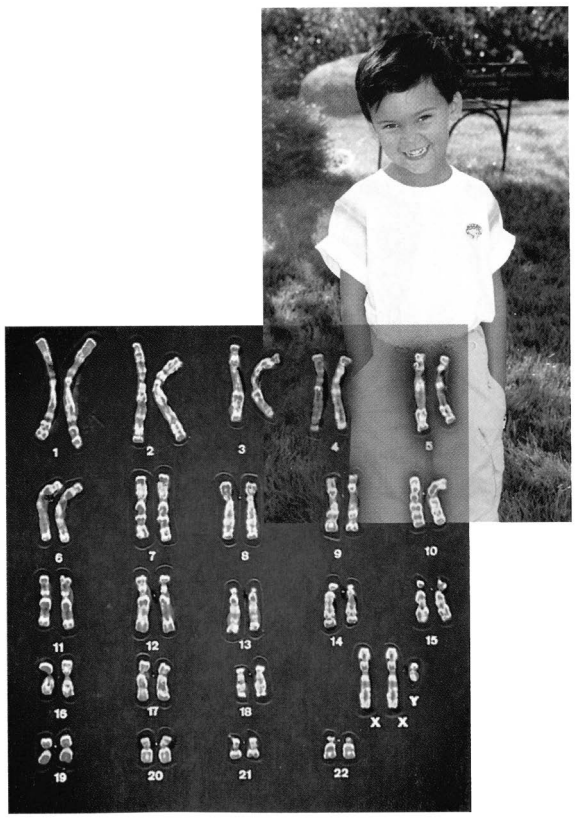
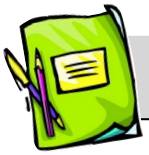


Photo credit: © CNRI/SPL/Photo Researchers, Inc.; Courtesy Richard Shelton/Klinefelter Syndrome & Associates

Source: Mader, Sylvia S. *Inquiry into Life.* 11th ed. New York, NY: McGraw-Hill, Higher Education, 2006. 526.



Learning Activity 1.5: Nondisjunction and Karyotypes

This learning activity will give you an opportunity to review what you have learned about nondisjunction and karyotypes. Please record your responses in your notebook.

1. What is *nondisjunction*? When does its occurrence cause the most severe problems?
2. What is the difference between a *monosomy* and a *trisomy*?
3. What is a *karyotype*, and how is it used in genetics?

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 1.5. The assignment details can be found after the Lesson Summary.

Lesson Summary

In Lesson 5, you have learned about how chromosomal mutations can result from the nondisjunction of chromosomes during cell division. You have learned about autosomal nondisjunction and about nondisjunction of the sex chromosomes. You have studied the conditions caused by monosomies and trisomies in an embryo following fertilization. In addition, you have learned about how karyotypes are prepared and about some of the uses of information based on karyotypes.

As this module has emphasized, human understanding of genetics continues to grow at an incredible pace; as our understanding grows, we must also be prepared to deal with ethical dilemmas and choices that follow from that understanding. In this lesson, you have started to consider some of these issues and to form opinions regarding them. It is a challenge to you to be aware of how knowledge about genetics changes over time and about how that growing knowledge is used in the development of new genetic technologies.

Assignment 1.5: Nondisjunction and Karyotypes (13 marks)

Please respond to the following assignment questions in the space provided. Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 1.

1. Recall the discussion of amniocentesis from Lesson 4 of this module, and consider some of the chromosomal mutations due to nondisjunction that you learned about in Lesson 5. How is the process of karyotyping useful when screening for genetic conditions such as Down syndrome? *(2 marks)*

2. Do you think it is ethically acceptable for a couple to have amniocentesis done during pregnancy to find out whether their child has a chromosomal mutation? Explain your position regarding this issue. *(3 marks)*

(continued)

Assignment 1.5: Nondisjunction and Karyotypes (continued)

3. Genetic screening is available for conditions such as Turner syndrome and Klinefelter syndrome. Do you think that **mandatory genetic testing** for these conditions and any others caused by monosomies and trisomies should be required during pregnancy? Explain your position regarding this issue. *(3 marks)*

4. Explain how a normal male and a normal female can have a child with the XYY condition. Explain how the same parents could have a child with the XXY condition. *(5 marks)*

Module 1 Summary

Congratulations! You have finished the first module of this course.

Submitting Your Assignments

It is now time for you to submit your assignments from Module 1 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 1 assignments and organize your material in the following order:

- ❑ Cover Sheet for Module 1 (found at the end of the course Introduction)
- ❑ Assignment 1.1: Introduction to Genetics
- ❑ Assignment 1.2: Making Predictions in Genetics
- ❑ Assignment 1.3: Sex-Linked Traits
- ❑ Assignment 1.4: Pedigree Charts and Genetic Testing
- ❑ Assignment 1.5: Nondisjunction and Karyotypes

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

Notes

Module 1 Summary

Congratulations! You have finished the first module of this course.

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- ❑ Assignment 1.3: Sex-Linked Traits
- ❑ Assignment 1.4: Pedigree Charts and Genetic Testing
- ❑ Assignment 1.5: Nondisjunction and Karyotypes

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

Notes

Grade 12 Biology (40S)

Module 1
Understanding Biological Inheritance

Learning Activity Answer Key

MODULE 1:
UNDERSTANDING BIOLOGICAL INHERITANCE

Learning Activity 1.1: Introduction to Genetics

This learning activity gave you an opportunity to review and practise what you had learned about genetics in Lesson 1.

1. Assume that, in garden peas, round seeds are the dominant trait and wrinkled seeds are the recessive trait. The alleles for this trait are *R* for round and *r* for wrinkled.

   a) What is the genotype of a plant with wrinkled seeds?

   rr

   b) What is the genotype of a plant with round seeds?

   Either *RR* or *Rr*

   c) What is the genotype of a hybrid plant?

   Rr

   d) What is the genotype of a purebred plant?

   Either *RR* or *rr*

   e) What is the genotype of a heterozygous plant?

   Rr

   f) What is the genotype of a homozygous plant?

   Either *RR* or *rr*

   g) What is the genotype of a homozygous dominant plant?

   RR

   h) What is the phenotype of a hybrid plant?

   Round seeds

   i) What is the phenotype of a homozygous recessive plant?

   Wrinkled seeds

   j) If a parent plant with the genotype *Rr* produces gametes, what genes will the gametes carry?

   Each gamete will be either *R* or *r*.

   k) If a plant has the genotype *Rr*, did it receive the *R* allele or the *r* allele from its female parent?

There is no way to determine this unless the genotypes/phenotypes of the parents are known.

2. Name the three laws of inheritance that Gregor Mendel discovered while studying pea plants. Briefly define each law.
   - **The law of dominance:** When homozygous parents with different alleles for a given trait are crossed, the effect of one gene is sometimes seen in the offspring, while the effect of the other gene is masked. The gene whose effect is seen is dominant over the gene whose effect is not seen. The gene that is masked is said to be recessive.
   - **The law of segregation:** Paired genes separate during meiosis so that each haploid gamete has only one gene for a given trait. Genes from both parents then recombine at random during fertilization.
   - **The law of independent assortment:** The inheritance pattern of one trait will not affect the inheritance pattern of another. Maternal and paternal chromosomes segregate independently of each other during the formation of haploid gametes.

Learning Activity 1.2: Making Predictions in Genetics

This learning activity gave you an opportunity to review and practise what you had learned about making predictions in genetics.

1. Recall that in pea plants, tall is dominant and short is recessive. Call the two alleles *T* (tall) and *t* (short).

   a) What are the genotypes of the parents if both are homozygous and one is tall while the other is short?

   The parents are *TT* and *tt*.

   b) Draw a Punnett square to predict the genotypes of the offspring that these two parents could produce.

		Parent #1	
		T	*T*
Parent #2	*t*	*Tt*	*Tt*
	t	*Tt*	*Tt*

   c) What are the possible genotypes of the offspring?

   There is only one possible genotype: *Tt*.

   d) What are the possible phenotypes of the offspring?

   There is only one possible phenotype: tall.

   e) The two original parents, *TT* and *tt*, are members of the P generation. What is the name of the generation shown in the Punnett square that you just drew?

   This set of possible offspring is the F_1 generation.

f) Draw a Punnett square illustrating the cross between two members of the F_1 generation.

		Parent #1	
		T	*t*
Parent #2	*T*	*TT*	*Tt*
	t	*Tt*	*tt*

g) What are the possible genotypes of the offspring, and in what ratio do they appear?

The genotypes are: 1 *TT* : 2 *Tt* : 1 *tt*.

h) What are the possible phenotypes of the offspring, and in what ratio do they appear?

The phenotypes are: 3 tall : 1 short.

i) To which generation do the offspring shown in the Punnett square belong?

These offspring belong to the F_2 generation, since their parents belong to the F_1 generation.

2. Human blood type is controlled by multiple alleles. Two of the three possible alleles are co-dominant and one possible allele is recessive to both the others. The alleles can be called I^A for type A blood, I^B for type B blood, and *i* for type O blood.

a) What is the genotype of a person with homozygous type A blood?

The genotype is I^AI^A.

b) What is the genotype of a person with homozygous type B blood?

The genotype is I^BI^B.

c) What phenotype would a person with genotype I^AI^B show?

The person would show type AB blood.

d) What is the genotype of a person with type O blood?

The genotype is *ii*.

e) A man with type A blood and a woman with type B blood have a child with type O blood. How is that possible if the alleles for type A blood and type B blood are both dominant?

The man had genotype I^Ai and the woman had genotype I^Bi. Their child had genotype *ii*. Each parent was a carrier for the recessive trait.

Learning Activity 1.3: Sex-Linked Traits

This learning activity gave you an opportunity to review and practise what you had learned about sex-linked traits.

1. A couple has four children, all of whom are boys. What is the chance that their next child will be a girl?

   The probability of their next child being a girl is 50 percent. The chance of any one child being a certain sex is unaffected by the birth of previous children.

   This cross is shown in the Punnett square below.

   XY × XX

	X	X
X	XX	XX
Y	XY	XY

   There is a 50–50 chance of having either a boy or a girl.

2. Duchenne muscular dystrophy (DMD) is a recessive, sex-linked disorder. A man and a woman who are both free of the disorder have two children. Their elder son develops DMD, while their younger son is free of the disorder. Let the recessive gene be X^m and the dominant gene by X^M.

   a) Determine the genotypes of the parents.

      The father is not affected. His genotype is X^MY. To have a son with the disorder, the mother must be a carrier. Her genotype is X^MX^m.

This cross is show in the Punnett square below.

$X^MY \times X^MX^m$

	X^M	X^m
X^M	X^MX^M	X^MX^m
Y	X^MY	X^mY

b) Determine the genotypes of the children.

The elder son is affected by DMD. His genotype is X^mY.

The younger son is free of the disorder. His genotype is X^MY.

3. A woman whose father was red-green colour-blind and a man with no history of colour-blindness in his family plan to start a family. What is the chance that they will have children who are colour-blind? Let the recessive gene be X^c and the dominant gene be X^C.

The father is not colour-blind. His genotype is X^CY.

The mother is not colour-blind, but inherited the gene for colour-blindness from her father. She is a carrier, with genotype X^CX^c.

This cross is shown in the Punnett square below.

$X^CY \times X^CX^c$

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

There is a 50 percent chance that their sons will be colour-blind. None of their daughters will be colour-blind.

4. Given the following data, determine the inheritance pattern of black, orange, and calico coat colour in cats.

   Hints: male cats are XY and female cats are XX. Calico is a mix of orange and black fur.

Cross	Parents	Offspring (ratio of)
#1	black male × orange female	1 orange male: 1 calico female
#2	orange male × black female	1 black male: 1 calico female
#3	orange male × calico female	1 black male: 1 orange male: 1 orange female: 1 calico female

As calico is a mix of orange and black, the genes for orange and black coat colour are co-dominant. Let C = black, C' = orange, and CC' = calico. However, there are no male calico cats. Therefore, coat colour must be sex-linked.

Punnett squares for the three crosses are shown below.

Cross #1: black male (X^CY) × orange female ($X^{C'}X^{C'}$)

	$X^{C'}$	$X^{C'}$
X^C	$X^CX^{C'}$	$X^CX^{C'}$
Y	$X^{C'}Y$	$X^{C'}Y$

1 orange male: 1 calico female

Cross #2: orange male ($X^{C'}Y$) × black female (X^CX^C)

	X^C	X^C
$X^{C'}$	$X^CX^{C'}$	$X^CX^{C'}$
Y	X^CY	X^CY

1 black male: 1 calico female

Cross #3: orange male ($X^{C'}Y$) × calico female ($X^{C}X^{C'}$)

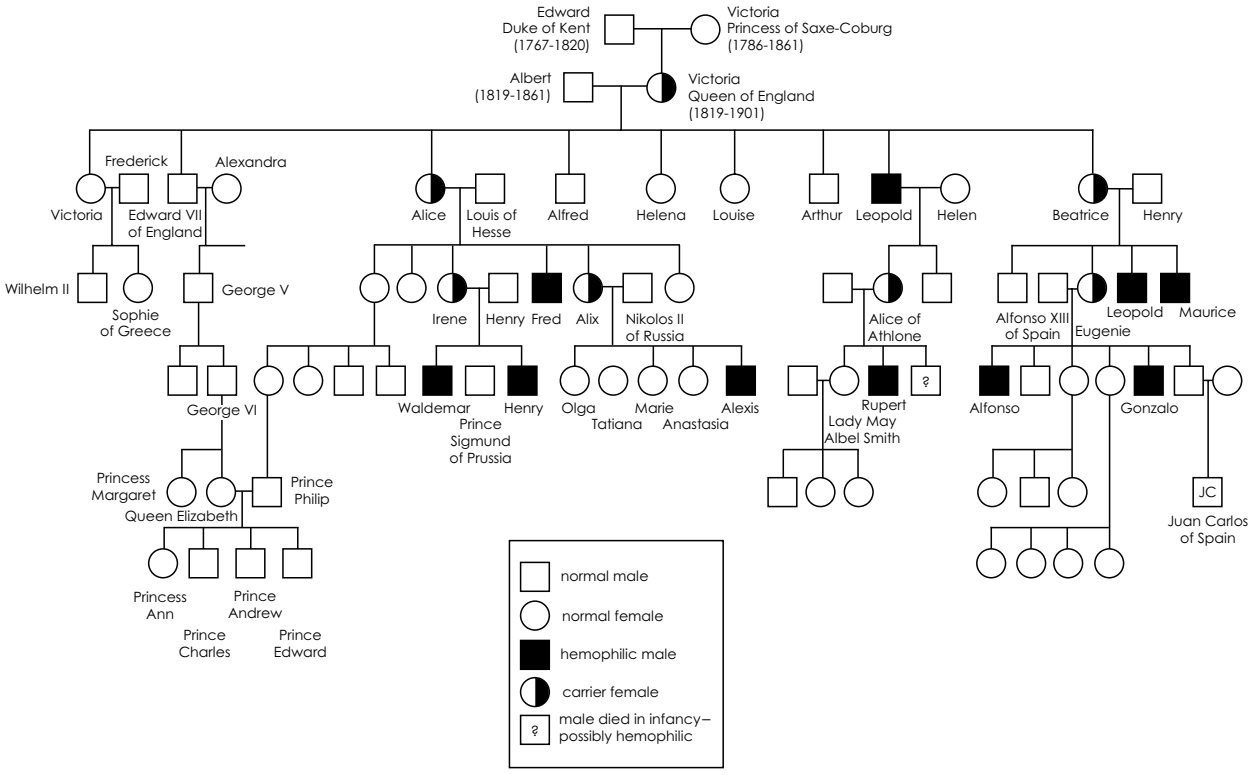
	X^{C}	$X^{C'}$
$X^{C'}$	$X^{C}X^{C'}$	$X^{C'}X^{C'}$
Y	$X^{C}Y$	$X^{C'}Y$

1 black male: 1 orange male: 1 orange female: 1 calico female

Learning Activity 1.4: Human Pedigree Charts

In this learning activity, you considered the pedigree chart entitled Pedigree of Queen Victoria and Her Descendants (Figure 1.9). You used this chart to answer the questions that follow.

Figure 1.9 **Pedigree Chart of Queen Victoria and Her Descendants**



Source: Aronova-Tiuntseva, Yelena, and Clyde Freeman Herreid. "Hemophilia: 'The Royal Disease.'" 20 Sept. 2003. *Case Collection*. www.sciencecases.org/hemo/hemo.pdf. Copyright held by National Center for Case Study Teaching in Science, University at Buffalo, State University of New York, all rights reserved. Reproduced with permission.

In this context, the term *normal* refers to an individual who has the clotting mechanism in the blood, whereas someone with hemophilia does not have this clotting mechanism.

1. How many daughters did Queen Victoria and her husband, Albert, have? How many sons? Did any of their children have hemophilia? If so, what were their names?

   Queen Victoria and her husband had five daughters and four sons. One of their children, Leopold, had hemophilia.

2. If neither Queen Victoria nor Albert had hemophilia, how could any of their descendants have the disease?

   It is believed that Queen Victoria was a carrier for this recessive sex-linked trait. Albert's genotype was X^HY and Victoria's was X^HX^h. As a result, all their daughters were normal (did not have hemophilia) but two of them, Alice and Beatrice, were heterozygous for the trait and, therefore, had the ability to pass the recessive gene on to their children. Of Victoria's four sons, only one had hemophilia; Leopold received the recessive sex-linked gene from his mother and a Y chromosome from his father. The other three sons, Edward, Alfred, and Arthur, were all normal and did not pass on the gene to their children.

3. Consider Leopold and his wife, Helen. Leopold died at the age of 31 after a minor fall. He had suffered repeatedly from severe hemorrhages during his life and was always under careful watch to reduce the chance of injury. Leopold and Helen had one daughter, Alice of Athlone, and one son. Alice of Athlone was a carrier for the recessive gene and her husband was normal. They had three children, a daughter and two sons. One son, Rupert, had hemophilia. The other son and the daughter were of unknown genotype. What is the probability that their other son had hemophilia? What is the probability that their daughter had hemophilia? What is the probability that their daughter was a carrier, like her mother?

   The other son's mother, Alice of Athlone, was a carrier. So there is a 50 percent chance that he had hemophilia and a 50 percent chance that he did not. The father of both children was normal. So the daughter was normal, regardless of whether she was heterozygous or homozygous. There is a 50 percent chance that she was X^HX^H (receiving the dominant gene that her mother possessed) and a 50 percent chance that she was X^HX^h (receiving the recessive gene from her mother and the dominant gene from her father).

4. Since the present royal family is descended from Edward VII of England, explain why hemophilia is not seen in those descendants.

   Edward married Alexandra, whose family history did not include hemophilia. Therefore, it is likely that her genotype was X^HX^H, since the recessive gene in this case is rare in the population as a whole. Edward did not have hemophilia, so his genotype was X^HY. Therefore, the X^h gene did not exist in either parent, so they could not have passed it on to their children.

5. Now consider Victoria's youngest daughter, Beatrice, who married Henry and had four children, one normal daughter, one normal son, and two sons with hemophilia. The daughter, Eugenie, married Alfonso XIII of Spain and had six children—two normal daughters, two normal sons, and two sons with hemophilia. Are you surprised by the pedigree that indicates that neither daughter had children with hemophilia? Explain.

   No, this is not surprising. Their mother was a carrier for the gene and their father was normal. So there was a 50 percent chance that each of the daughters was homozygous dominant and a 50 percent chance that each of the daughters was heterozygous. If they were homozygous and married normal men, none of their children would have hemophilia. If they were heterozygous and married normal men, 50 percent of their daughters and none of their sons would be expected to have hemophilia. It is possible that they could have given birth to homozygous dominant daughters and normal sons.

Learning Activity 1.5: Nondisjunction and Karyotypes

This learning activity gave you an opportunity to review what you had learned about nondisjunction and karyotypes.

1. What is *nondisjunction*? When does its occurrence cause the most severe problems?

   Nondisjunction occurs when two homologous chromosomes move to the same pole during meiosis. The result is that one of the daughter cells produced will have an extra chromosome and the other daughter cell will be missing one of the chromosomes. Cells that either lack genetic information or have too many copies of some information are likely not to function correctly. Although nondisjunction can occur whenever cells divide, it has most profound effects when it occurs during the formation of gametes.

2. What is the difference between a *monosomy* and a *trisomy*?

   - A *monosomy* results when a sex cell containing 22 chromosomes joins with a normal sex cell; the resulting zygote has 45 chromosomes instead of the normal diploid number of 46.
   - A *trisomy* results when a sex cell containing 24 chromosomes joins with a normal sex cell; the resulting zygote has 47 chromosomes instead of the normal diploid number of 46.

3. What is a *karyotype,* and how is it used in genetics?

   A *karyotype* is a picture of the chromosomes arranged in homologous pairs in a predictable pattern. A karyotype is useful in determining whether a cell has its normal set of chromosomes. It clearly shows monosomies and trisomies when they occur.

Notes

Biology Videos

Module 1

1. Gregor Mendel and the Principles of Inheritance
2. Video - Gregor Mendel's Principles of Inheritance
3. Video - Learn Biology: How to Draw a Punnett Square
    a. A Punnett square is used to predict the chances of an offspring to have its parents' traits. These squares are most commonly divided into four parts, with each part equalling a 25% chance of the offspring receiving that set of genes. More complicated squares may have more than four parts, though the same basic method applies. The letters surrounding and within each square represent alleles. They are one part of a gene pair occupying a specific part of a chromosome. All dominate alleles have capital letters, while the recessive ones are lowercase. Dominate alleles will always overpower recessive ones in the expression of the gene.
4. Video - Sex Chromosomes and Sex-Linked Traits
5. Video - Sex-Linked Traits
6. Ethical issues in predictive genetic testing: a public health perspective
7. Patterns of Inheritance
8. Genetic Testing FAQ
9. Pedigree Analysis in Human Genetics: Inheritance Patterns
10. What is a gene mutation and how do mutations occur?
11. An introduction to genetic mutations
12. Video - DNA Mutations | Genetics | Biology
13. Video - Mutations: The Potential Power of a Small Change
14. Video - Chromosomal Abnormalities and Non-Disjunction
15. Video - Chromosomes and Karyotypes

Grade 12 Biology (40S)

Module 2
Mechanisms of Inheritance

Module 2:
Mechanisms of Inheritance

Introduction

Do you love the smell of homemade bread? Do you enjoy making bread yourself? Of the many types of breads that can be made using various recipes and techniques, some are yeast breads. These breads rise because of the presence of yeast, an important ingredient familiar to bread makers all over the world.

How does yeast work to make bread rise? Yeast breads rise because of the presence of microscopic yeast cells in the bread dough that generate tiny bubbles of gas as they grow. The warm water and nutrients with which the yeast cells are combined provide what the microscopic cells need to grow.

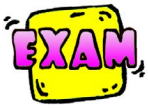
In Module 1 of this course, you gained an understanding of biological inheritance. In Module 2, you will learn how biological inheritance works. You will discover how genes cause traits to appear. The link between genotype and phenotype is one of the most amazing connections in biology. Also, you will see how a change in genotype, a mutation, can cause a change in phenotype. In the previous module, it was possible for you to learn about biological inheritance without understanding the mechanisms that explain how it occurs. In this module, your goal will be to understand the underlying mechanisms of inheritance.

Module 2 Assignments

When you have completed the assignments for Module 2, submit your completed assignments to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 2.1	The Discovery of DNA
2	Assignment 2.2	The Structure of DNA
3	Assignment 2.3	Replication, Transcription, and Translation
4	Assignment 2.4	Genetic Mutations
5	Assignment 2.5	Applications of Genetic Knowledge

Writing Your Midterm Examination



You will write the midterm examination when you have completed Module 2 of this course. The midterm examination is based on Modules 1 and 2, and is worth 20 percent of your final mark in the course. To do well on the midterm examination, you should review all the work you complete in Modules 1 and 2, including all the learning activities and assignments. You will write the midterm examination under supervision.

Lesson 1: The Discovery of DNA

Lesson Focus

In this lesson, you will

- ❑ outline significant scientific contributions/discoveries that led to the current understanding of the structure and function of the DNA molecule

  Include: timeline, individual contributions, multidisciplinary collaboration, and competitive environment

Introduction

In Module 1, you learned about the work of Gregor Mendel, including his discovery of the fundamental laws of inheritance, which are still useful today. Mendel did not know the mechanisms of inheritance, however, because he did not know what his factors (now known as genes) were or where they were located in the cell. A number of scientists who worked more with microscopes and biochemistry than with garden peas discovered information about how inheritance works. It is their work that you will study in this lesson.

The Discovery of DNA

The work of scientists from around the world has led to our current understanding of the structure and function of DNA. A brief overview of their work will help you to understand their contributions and how each discovery provided another piece in the puzzle.

Work in the Late 1800s

Some of the scientists who worked to understand the mechanisms of inheritance made their most significant contributions in the late nineteenth century.

- **Friedrich Miescher (1844–1895):** At the University of Tübingen in Germany, Miescher was given the task of trying to isolate the chemicals that made up white blood cells; he collected bandages from a nearby clinic and successfully isolated a new molecule, which he called *nuclein*. His paper was published in 1871. His early work with nuclein was actually the first isolation of DNA, although he did not believe that it was the chemical of heredity.

- **Carl Correns (1864–1933):** Correns attended the University of Munich, where he continued Mendel's study of the genetics of garden peas; he successfully and clearly restated Mendel's laws of heredity in 1900, taking little credit for his own contributions.
- **Hugo de Vries (1848–1935):** A botany professor, de Vries did most of his hybridization experiments without knowing of Mendel's work with garden peas. Based on his own work, de Vries reached the same conclusions as Mendel. His paper was first published in 1900.
- **Erich von Tschermak-Seysenegg (1871–1962):** Erich von Tschermak-Seysenegg did plant breeding experiments using peas. In 1900, he published his work, in which he independently proposed the same laws of inheritance that Mendel, Correns, and de Vries had discovered. With Correns and de Vries, von Tschermak-Seysenegg is recognized as one of the three re-discoverers of Mendel's laws of inheritance.

Work in the Early and Mid-1900s

Some of the scientists who worked to understand the mechanisms of inheritance made their most significant contributions in the first half of the twentieth century.

- **Thomas Hunt Morgan (1866–1945):** Morgan first suggested the *chromosomal theory of inheritance*, based on his work with the inheritance patterns of fruit flies belonging to the genus *Drosophila*. He and his students proposed the chromosomal theory of inheritance, which included the concepts of genetic linkage, chromosomal crossing over, and nondisjunction.
- **Hermann Muller (1890–1967):** Muller, a student working with Morgan, published a paper in 1915 suggesting that mutations in one gene could alter the expression of another gene. Later, Muller showed that X-rays could induce mutations.
- **Barbara McClintock (1902–1992):** At Cornell University, McClintock showed in 1929 that chromosomal crossovers happen in corn chromosomes; she later learned that X-rays could cause translocations, inversions, deletions, and ring chromosomes in corn.
- **George Wells Beadle (1903–1989)** and **Edward Lawrie Tatum (1909–1975):** In 1937, Beadle joined Tatum at Stanford University, where they studied inheritance in *Neurospora* (bread mould). Beadle and Tatum studied how the mutation of a single gene could control the production of a particular enzyme; their "one gene—one enzyme" hypothesis was very important.

- **Oswald Theodore Avery (1877–1955):** In 1928, Avery, an English bacteriologist, discovered *transformation* in bacteria by studying a strain known to cause pneumonia. He proved that cell fragments of dead, disease-causing bacteria could still cause pneumonia when allowed to come in contact with harmless bacteria. It was later found that the agent of bacterial transformation was DNA.
- **Rosalind Elsie Franklin (1920–1958):** Franklin produced the X-ray crystallography pictures of DNA that were later used by Francis Crick and James Watson when they determined the three-dimensional chemical structure of DNA. She presented her data at a lecture at King's College in 1951, at which Watson was in attendance.
- **Alfred Day Hershey (1908–1997)** and **Martha Chase (1927–2003):** While at the Carnegie Institution of Washington's Department of Genetics at Cold Spring Harbor, Hershey and Chase studied a type of virus called a *phage* or *bacteriophage*, which attacks bacteria. During the early 1950s, they showed that viral DNA contained the information for how to produce more viruses. This work provided even more evidence that genes are made of DNA.

Work in the Late 1900s

Some of the scientists who worked to understand the mechanisms of inheritance made their most significant contributions in the late twentieth century.

- **Arthur Kornberg (1918–2007):** In 1953, Kornberg successfully isolated the enzyme that is involved in DNA replication. During his career, he isolated and identified over a hundred enzymes used in metabolic reactions.
- **François Jacob (1920–)** and **Jacques Lucien Monod (1910–1976):** In 1954, Jacob and Monod worked on the *lac operon* model—the idea that genes for protein synthesis could be turned "on" and "off." This idea helped to explain the regulation of protein synthesis that earlier researchers were looking for.
- **Sydney Brenner (1927–):** In 1956, Brenner wrote a proof that used statistics and amino acid protein sequences to show that three nucleotides code for one amino acid. His research also showed that genetic mutations correlate with changes in the amino acid sequence.
- **Paul Charles Zamecnik (1913–2009)** and **Mahlon Hoagland (1921–):** In 1957, Zamecnik and Hoagland successfully determined the identity of Crick's adaptor molecule, transfer RNA (tRNA). They also used radioactive isotopes to prove that proteins were built from amino acids in a process that required energy in the form of adenosine triphosphate (ATP).

- **Matthew Stanley Meselson (1930–)** and **Franklin Stahl (1929–):** By 1957, Meselson and Stahl had experimental proof that Watson and Crick's initial ideas about how DNA copied itself during replication were indeed verifiable. They did this by inventing a new technique called *density gradient centrifugation*. In the fall of 1960, Meselson discovered how a cell recognizes its own DNA by attaching methyl groups to it; foreign DNA is routinely attacked and destroyed by cellular enzymes.
- **Frederick Sanger (1918–):** Sanger was the first person to isolate and identify a protein sequence. He showed that a protein molecule is an ordered molecule; he also suggested that DNA and genes must be ordered as well. In 1958, he won the Nobel Prize for Chemistry.
- **Marshall Nirenberg (1927–):** In 1961, Nirenberg and his colleagues at the National Institutes of Health showed that a triplet of nucleotides in an RNA molecule could code for a particular amino acid. They deciphered the entire genetic code by matching amino acids to triplet nucleotides in the years that followed. They also showed that, with a few exceptions, the code they had determined was universal to all life on Earth.
- **Francis Harry Compton Crick (1916–2004)** and **James Dewey Watson (1928–):** These two scientists correctly proposed the chemical structure of DNA. They used X-ray crystallography and physical models to understand the double helix nature of the DNA molecule. In 1962, they shared the Nobel Prize for Physiology or Medicine for their work. In 1968, Watson published his book, *The Double Helix: A Personal Account of the Discovery of the Structure of DNA*. From 1988 to 1992, Watson ran the Human Genome Project at the National Institutes of Health. He also made Cold Spring Harbor Laboratory one of the world's leading research facilities for molecular genetics, cancer, and neurobiology research.
- **Seymour Benzer (1921–2007):** As a biology professor at California Institute of Technology (Caltech), Benzer and a graduate student named Ronald Konopka were the first researchers to find a gene that controls an organism's sense of time. This gene exists in fruit flies (*Drosophila*).
- **Stanley Norman Cohen (1935–)** and **Herbert W. Boyer (1936–):** In 1972, Cohen and Boyer worked together to develop early ideas about recombinant DNA technology. They did this by working with bacteria that had been "transformed" by the introduction of new DNA. This work was later patented.
- **Richard John Roberts (1943–):** During the l970s and 1980s, Roberts and his colleagues identified about 75 enzymes that could cut DNA into manageable sizes to be used in sequencing. Roberts also helped to develop one of the first computer programs that maps and analyzes DNA fragments. He was an early proponent of using computers in molecular biology—a very important technique in the years since then.

- **Mario Renato Capecchi (1937–):** Capecchi's graduate advisor at Harvard was James Watson. In 1980, Capecchi studied how the genetic information in cells could be mutated. The technique enables researchers to generate mice with human diseases for study.
- **Stephen Fodor (1953–):** In 1989, Fodor was hired by Affymax Research Institute in Palo Alto, California. There, he invented the first DNA GeneChip®, which is used for large-scale gene studies.
- **Francis Collins (1950–):** In 1989, Collins successfully identified the gene that causes cystic fibrosis. Collins has been the director of the National Human Genome Research Institute since 1993. The Human Genome Project was launched in 1990.
- **John Sulston (1942–):** Sulston's work has focused primarily on the nematode worm (*Caenorhabditis elegans*). Through a careful study of this worm, he has built a *cell-fate map* to show how cell differentiation and specialization occurs as the body develops. Sulston believes that genes should not be patented, since they are not invented. He has chosen to work as director on the publicly funded sequencing project at the Sanger Centre (now named the Wellcome Trust Sanger Institute). His findings are made public as soon as he summarizes them.
- **Mary-Claire King (1946–):** In 1990, King and her colleagues proved the existence of the first gene to be associated with hereditary breast cancer. The gene is now called BRCA-1.

Work Since 2000

Some of the scientists who worked to understand the mechanisms of inheritance have made their most significant contributions since 2000.

- **John Venter (1946–):** Venter successfully finished assembling the entire human genome in only three years. He used a technique that he invented called "whole genome shotgun sequencing" and, using the world's greatest sequencing computers, completed the task in 2000. Those involved in the public program, the Human Genome Project, and Venter's for-profit program had talked about collaborating, but repeated attempts failed.
- **Human Genome Project:** The announcement that the Human Genome Project (HGP) was completed occurred on April 14, 2003. The International Human Genome Sequencing Consortium, led in the United States by the National Human Genome Research Institute (NHGRI) and the Department of Energy (DOE), announced that the project was completed more than two years ahead of schedule. The project was completed 50 years after the publication of Watson and Crick's important paper about DNA's double helix. James Watson was the first leader of the HGP. The project covers about 99 percent of the human genome's gene-containing regions and

has been sequenced to an accuracy of 99.99 percent. All the sequence data generated by the HGP has been deposited into public databases and made freely available to scientists around the world, with no restrictions on its use or redistribution. In 1990, only about 100 human disease genes had been identified; in 2003, that number had grown to about 1400 genes. Under the guidance of James Watson, the HGP was the first large scientific undertaking to dedicate a portion of its annual budget for research to the ethical, legal, and social implications (ELSI) of its work.

Learning Activity 2.1: A Timeline of the Discovery of DNA

For this learning activity, you will consider how our understanding of the mechanics of inheritance has changed over the last 150 years or so.

1. Construct a timeline that chronologically outlines major scientific discoveries that have led to our current understanding of DNA, and name the scientists who made the discoveries. Begin with Gregor Mendel and continue up to the present.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 2.1. The assignment details can be found after the Lesson Summary.

Lesson Summary

This lesson provided an overview of the work of scientists from the late 1800s to the present that has contributed to our understanding of the structure and function of the DNA molecule. In the next lesson, you will learn more about the structure of this molecule.

Assignment 2.1: The Discovery of DNA (20 marks)

Please read all the instructions for this assignment before you begin your work. Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 2.

1. Consider the work of the research scientists presented in this lesson. The work of each scientist was greatly influenced by the work of the other researchers who came before him or her. Below you will find three pairs of researchers listed:

   - **Carl Correns** and **Thomas Hunt Morgan**
   - **George Wells Beadle/Edward Lawrie Tatum** and **Sydney Brenner** (consider Beadle and Tatum as one researcher for the purposes of this assignment)
   - **Marshall Nirenberg** and **Francis Collins**

   Choose **two pairs** of these researchers and, for **each** pair, do the following. *(20 marks total—10 marks for each comparison)*

   a) Research how the work done by the first person(s) **affected** the work of the following person. In other words, explain the **connection** that existed between the scientists in each pair in terms of their research. You can do this by describing the work of the first person(s), then describing the work of the second person, and then describing the link between the pair of scientists and their work. Do this for both pairs that you have chosen from the list above. Make clear, distinct points in your response. *(6 marks—1 mark for each clear, distinct point)*

   b) Link the work done by each pair of scientists to work that has been done since their time. In other words, describe the work that resulted from the work of the pairs that you have chosen. Make clear, distinct points in your response. *(2 marks—1 mark for each clear, distinct point)*

   c) Clearly list at least two sources you use in your research, including the following details (depending on what sources you use): *(2 marks)*

      - **Books:** author, title, place of publication, publisher, date of publication, pages
      - **Articles (from periodicals/journals):** author, article title, publication title, date of publication, pages
      - **Websites:** author, site name, website address, date of publication/update, date of access (provide as much information as you can find)

(continued)

Assignment 2.1: The Discovery of DNA (continued)

(continued)

Assignment 2.1: The Discovery of DNA (continued)

Notes

Lesson 2: The Structure of DNA

Lesson Focus

In this lesson, you will

- ❑ describe the structure of a DNA nucleotide
  Include: deoxyribose sugar, phosphate group, and nitrogenous bases
- ❑ describe the structure of a DNA molecule
  Include: double helix, nucleotides, base pairing, and gene

Introduction

In the previous lesson, you learned about the work of some of the scientists who have contributed to current knowledge about the mechanisms of inheritance. In particular, you saw their work focusing, over time, on a molecule called DNA. In this lesson, you will learn about the structure of this fascinating and very important molecule.

The Building Blocks of DNA

DNA stands for deoxyribonucleic acid. It is one of the nucleic acid molecules known to exist. DNA is a complicated molecule that consists of a chain of smaller molecules known as *nucleotides*. So, the building blocks of DNA are nucleotides.

Each nucleotide is a molecule made of three smaller molecules: a phosphate group, a five-carbon sugar, and a nitrogen-containing organic base. You will now look at each of these molecules separately.

Phosphate Group

The portion of a nucleotide that is the phosphate group consists of a central atom of phosphorus surrounded by three oxygen atoms and one hydroxide group, which is made up of an oxygen atom bonded to a hydrogen atom. So, the phosphate group is made of phosphorus, oxygen, and hydrogen.

Deoxyribose Sugar

The second structural component of DNA is *deoxyribose*, which is a simple, five-carbon sugar. Four of the carbon atoms and one oxygen atom form a five-sided ring that has hydrogen atoms and one more carbon atom bonded to it. This molecule is called a deoxyribose sugar because it has one fewer oxygen atom than a similar sugar, ribose, has. So, deoxyribose is made of carbon, hydrogen, and oxygen.

Nitrogen-Containing Organic Base

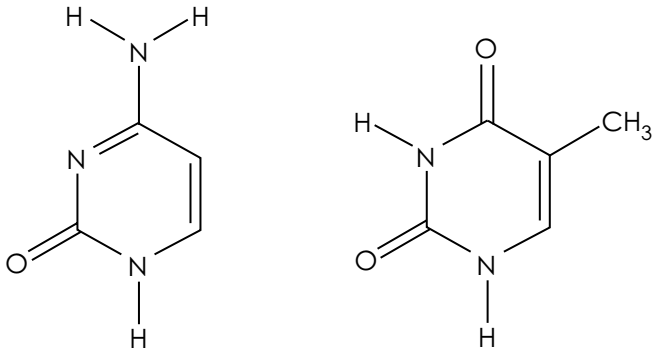
The third portion of the DNA molecule is a nitrogen-containing base that is also a ring-shaped molecule. Nitrogen-containing bases are said to be organic because those rings are primarily made of carbon. In DNA, four possible bases may be present in any one nucleotide. These four bases are adenine, thymine, guanine, and cytosine. For ease of discussion, these four bases are often referred to as A, T, G, and C.

The chemical makeup of the four nitrogen-containing bases is shown in Figures 2.1 and 2.2.

- **Pyrimidines:** cytosine and thymine

  Pyrimidines have one ring. Carbon atoms are not shown in the following diagram, but they are assumed to exist at the intersections that are not labelled.

Figure 2.1 ***Pyrimidines***

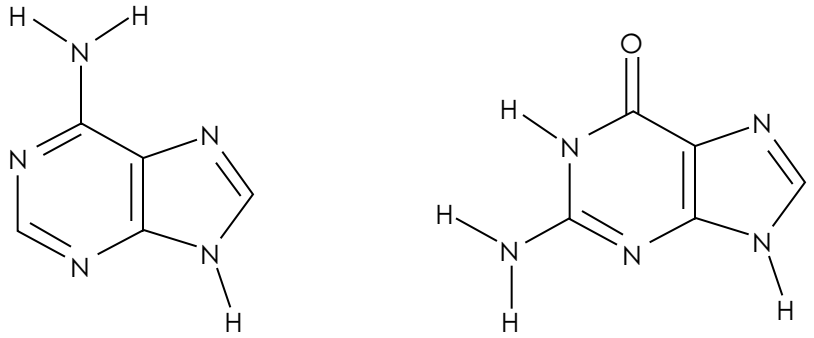


Cytosine (C) Thymine (T)

- **Purines:** adenine and guanine

  Purines have two rings. Again, carbon atoms are not shown in the following diagram, but they do exist at the unlabelled intersections.

Figure 2.2 ***Purines***



Adenine (A) Guanine (G)

Because each nucleotide contains one of four possible nitrogen-containing bases, there are four possible nucleotides. Each is made up of a phosphate group, a sugar molecule, and a base that can be A, T, G, or C. As you study the structure of the DNA molecule itself, you will see how these nucleotides are bonded together in a chain. The entire nucleotide is referred to as A, T, G, or C; however, remember that this refers to a nucleotide, and not just the base that is present in it.

The Double Helix

There is so much beauty in the biological world—beauty of symmetry and diversity. One of the most beautiful designs in nature is the design of the basic chemical that controls the genetics of nearly all the organisms on Earth. This chemical is DNA. Understanding its structure will help you to understand its function, and vice versa.

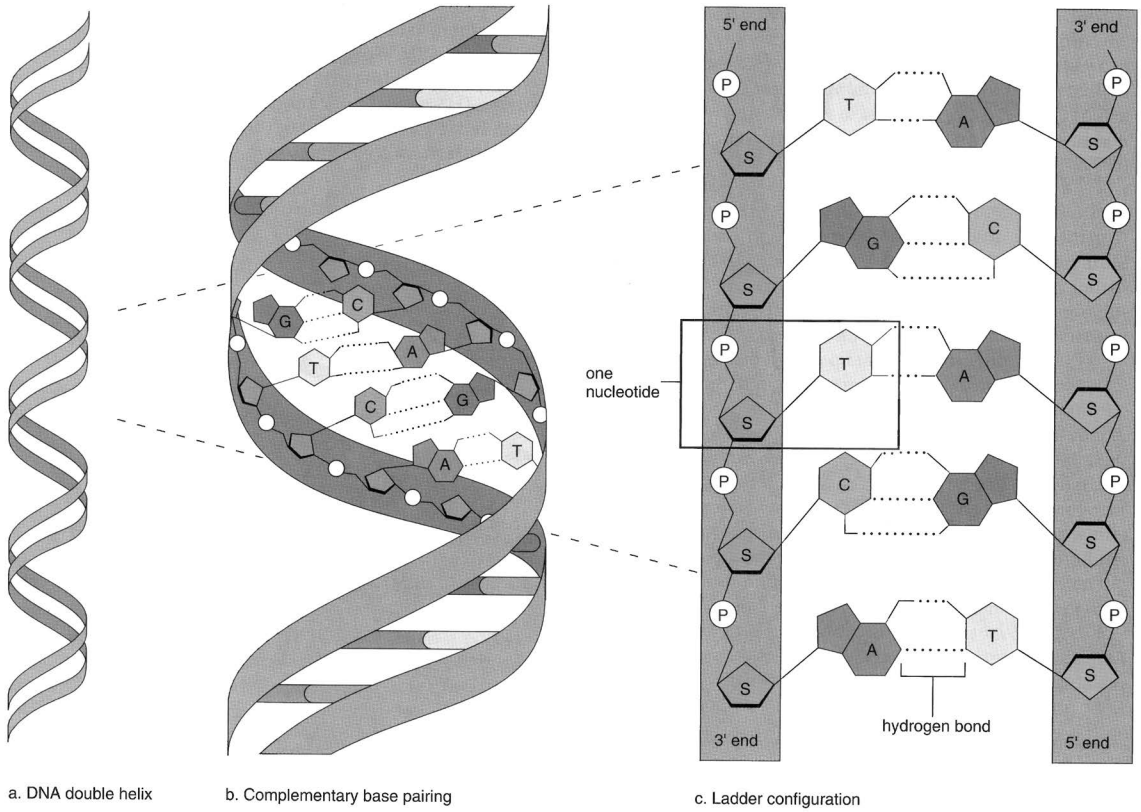
James Watson and Francis Crick were the two scientists credited with discovering the structure of DNA, the double helix. Their discovery was made public in 1953. Since 1953, scientists have continued to learn more and more about how DNA is made and how it works.

To picture the DNA molecule, imagine a rope ladder that has flexible sides, as opposed to rigid sides. Now imagine that the ladder is twisted so that it forms a spiral or helix. This twisting results in a set of flexible spirals with rigid rungs between them. That is the shape of the double helix: DNA.

The sides of this ladder are made up of alternating phosphate groups and sugar molecules. The rungs are each made of two nitrogen-containing bases. All the rungs are of the same width, keeping the ladder at a constant width throughout. In order for this to happen, the organic bases, A, T, G, and C, bond to each other in a very predictable way. Recall that the two pyrimidines—cytosine and thymine—have one ring, and the two purines—adenine and guanine—have two rings. Each pyrimidine bonds to one particular purine: adenine to thymine and guanine to cytosine. As a result, each rung has three rings in its structure. Because of the chemical structure of the four bases, the pairing is very predictable—A to T and G to C. The sides of the ladder are always made of alternating phosphate groups and sugar molecules. The phosphate groups are located on the outside of each side and the sugar molecules are located on the inside, bonded to the bases. The two bases in each rung are bonded to each other.

Consider an illustration of the DNA molecule in Figure 2.3.

Figure 2.3 **DNA Molecule**

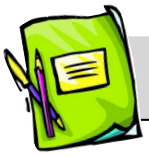


Source: Mader, Sylvia S. *Inquiry into Life.* 11th ed. New York, NY: McGraw-Hill, Higher Education, 2006. 40.

If you look closely at the illustration (ladder configuration on the right), you will notice that the two strands of the DNA molecule are oriented in opposite directions. That is, if the guanine nucleotide is "right side up" at the bottom of the molecule above, the cytosine nucleotide to which it is bonded is "upside down." If you compare the appearance of the final guanine nucleotide to the guanine nucleotide on the other strand and above it, you will see that they are oriented in opposite directions.

This illustration shows that the structure of the DNA molecule indeed consists of a "backbone" of phosphate groups and deoxyribose sugar molecules, while the "rungs" are made of nitrogen-containing bases. You can see that adenine bonds specifically to thymine and guanine bonds specifically to cytosine. Now imagine twisting the ladder (as shown in the illustration).

In the next lesson, you will learn about how the structure of DNA allows it to serve as the chemical of inheritance. Genes are made of DNA. So, in a way, DNA is like a recipe in that it codes for particular traits. That connection, between gene and trait, is one of the most fascinating ideas in the study of biology.



Learning Activity 2.2: The Structure of DNA

This learning activity will give you an opportunity to review what you have learned about the structure of DNA. Please record your responses in your notebook.

1. Suppose that the sequence of bases on one side of a DNA molecule is adenine, cytosine, thymine, guanine. What is the sequence of bases on the other side of each "rung" that matches it?
2. What chemicals are found in a nucleotide?
3. Who were the co-discoverers of the double-helix model of DNA?

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 2.2. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about the history of scientific understanding of the DNA molecule. Just as current knowledge is based on the research findings of many scientists, genetic research continues today; our understanding of how inheritance works continues to evolve. You have also learned in this lesson about the structure of the DNA molecule. This knowledge is important as you begin the next lesson, in which you will learn about how DNA is used by the cell to produce proteins. Proteins are the structural molecules that allow a cell to possess a particular form and function in the organism.

Assignment 2.2: The Structure of DNA (24 marks)

Please read all the instructions for this assignment before you begin your work. Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 2.

In this assignment, you will construct a small sequence of nucleotides to serve as a model of part of a DNA strand. Use the symbols shown in Figure 2.4 for each of the component parts.

Figure 2.4 **Symbols for Parts of Nucleotides**

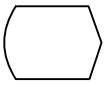
Deoxyribose sugar: 

Phosphate group: 

Adenine molecule: 

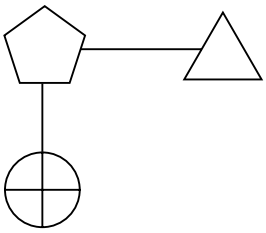
Thymine molecule: 

Guanine molecule: 

Cytosine molecule: 

So, for example, a nucleotide (which has three component parts) containing the base adenine would look like the one shown in Figure 2.5.

Figure 2.5 **Nucleotide Containing Base Adenine**

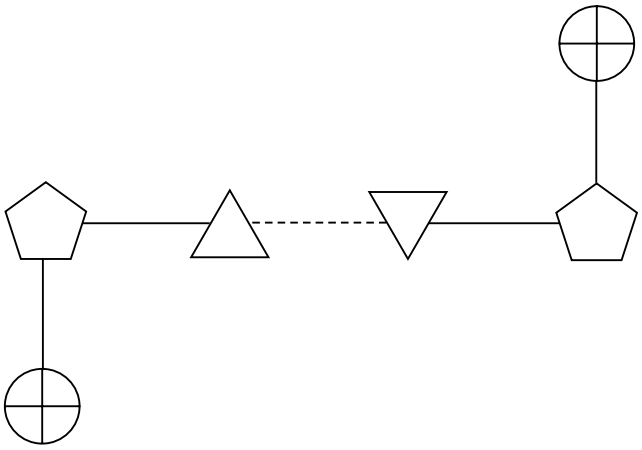


(continued)

Assignment 2.2: The Structure of DNA (continued)

If you were to draw an adenine nucleotide bonded to a thymine nucleotide (the two bases forming the "rung" of the ladder), you would draw a diagram similar to the one in Figure 2.6.

Figure 2.6 **Adenine Nucleotide Bonded to Thymine Nucleotide**



Note that the dotted line represents the bonding that connects two nucleotides across the "rung of the ladder."

Now, use the symbols provided to draw a portion of the DNA strand, as indicated by the following eight-base sequence. Remember to include all three portions of each nucleotide molecule. Show the bonding across each "rung" as a dotted line. *(24 marks total—3 marks for each of the eight base pairs)*

C – G

C – G

A – T

T – A

G – C

T – A

C – G

A – T

(continued)

Assignment 2.2: The Structure of DNA (continued)

(continued)

Assignment 2.2: The Structure of DNA (continued)

Lesson 3: Replication, Transcription, and Translation

Lesson Focus

In this lesson, you will

- ❑ describe the process of DNA replication
  Include: template, semi-conservative replication, and role of enzymes
- ❑ compare DNA and RNA in terms of their structure, use, and location in the cell
- ❑ outline the steps involved in protein synthesis
  Include: mRNA, codon, amino acid, transcription, tRNA, anticodon, ribosome, and translation

Introduction

In this lesson, you will learn about how DNA in the cell is used to build molecules that control how the cell looks and acts. In Module 1, you learned about genotypes and phenotypes as you used Punnett squares to predict the outcomes of genetic crosses. In this lesson, you will learn how the structure of DNA is used as a blueprint for the molecules produced by a cell. The molecules that a cell produces result in the traits that the cell displays. You will learn about the fundamental connection between gene and trait—between genotype and phenotype.

DNA Replication

In the previous lesson, you learned about the basic structure of the DNA molecule. The twisted ladder analogy provides a familiar visual picture that is useful for understanding a very complex molecule. Remember that a DNA molecule is made up of two chains of nucleotides. The sugar and phosphate molecules in these nucleotides form the two upright sides of the ladder. The organic bases in these nucleotides form the ladder's rungs. Organic bases bond to each other in predictable ways because of their chemical structure. The base called adenine (A) pairs only with thymine (T), while the base called guanine (G) pairs only with cytosine (C).

This background information now allows you to explore how the DNA molecule is used by the cell. You have learned that Mendel's *factors* are now called *genes*. Genes are made up of DNA, which holds the instructions for the cell about which molecules it should produce. Those molecules, coded for by the cell's DNA, control the cell's traits. Traits are both structural and functional; they are what the cell looks like and how it acts.

As an organism grows and repairs itself, it has to be able to make more cells. Remember that the first cell of a multicellular organism is called a *zygote*. That first cell that results from fertilization of the egg must reproduce itself. Furthermore, when this one cell reproduces, the two daughter cells that result must be identical to each other and identical to the parent cell. This process occurs millions of times as the developing embryo grows.

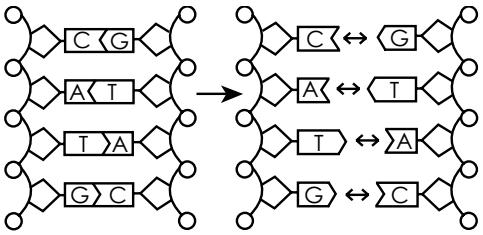
This process of one cell becoming two cells by cell division requires that the DNA in the parent cell be copied before the cell divides; otherwise, the daughter cells would each receive half of the genetic information that the parent cell possessed. The DNA in the parent cell actually copies itself once so that each daughter cell will receive exactly the same amount of DNA. It is essential that the copying process is accurate; the two copies must be identical to one another. This reproduction or copying of DNA is called *DNA replication*.

The replication of DNA involves three essential steps, which are described below.

1. **Base pairs separate.**

   If you imagine the DNA molecule as a twisted ladder, the first step in the replication of DNA consists of the base pairs that make up the rungs of the ladder separating from one another. The ladder separates down the middle. Another useful analogy is to imagine the DNA molecule like a twisted zipper. When replication begins, a portion of the DNA molecule "unzips." This process is shown in Figure 2.7.

Figure 2.7 **Base Pairs Separate**

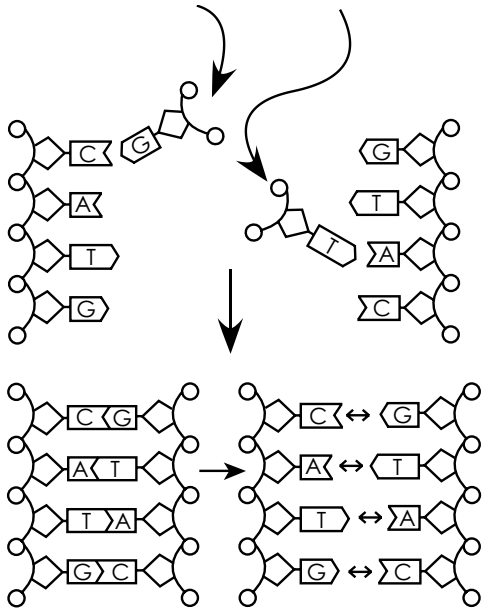


You see that the first step in DNA replication involves breaking down the rungs of the DNA ladder in the middle. The upright sides of the ladder pull apart, although not all at once. The process proceeds down the molecule, one base pair at a time.

2. **New bases move into position.**

   Once the base pairs on each side of the ladder are exposed, new nucleotides move into position next to them. The ladder structure is restored as the organic bases of new nucleotides bond to the exposed bases of the nucleotides from the original ladder. This process, which occurs on each side of the ladder, is shown in Figure 2.8.

Figure 2.8 **New Bases Move into Position**



Two new DNA molecules

Note that the predictable base pairings that you learned about in Lesson 2 of Module 2 still exist. If the base exposed is a T, the new nucleotide that moves into position possesses an A base. Each organic base has a complementary base. Organic bases exist in complementary pairs.

3. **Nucleotides are bonded together.**

   Once the new nucleotides have moved into position and the rungs have been re-formed, the sugar/phosphate sides of the ladder also bond together. Once the rungs have been rebuilt and the sides of the ladder have re-formed, the copying process is complete. Referring to the illustration in Figure 2.8, you can see that two ladders have been produced from one ladder. The two new ladders are identical to each other, as well as to the original ladder. DNA replication has successfully produced two new and identical molecules.

Note that half of each new ladder is made up of the "old" nucleotides and the other half is made up of "new" nucleotides. Therefore, DNA replication is said to be a *semi-conservative* process. There is no old strand or new strand; each strand (each ladder) is half old and half new. And the two ladders are identical. Replication has been accomplished.

When the two sides of the original ladder separate, exposing two chains of organic bases, the chain of old bases serves as a *template* in which new bases are attached. This idea of a template directing the formation of chemicals is a fundamental in the study of DNA. Each cell of an organism must possess the same genetic information. That information must be copied millions of times. It is essential that the copying process uses an existing (old) molecule as a pattern or template.

DNA replication is a process that would not occur without the involvement of enzymes. *Enzymes* are molecules that speed up chemical reactions in living cells. In the case of DNA replication, one enzyme causes the strands of DNA to separate, exposing the bases. Another enzyme recognizes the exposed bases and matches them up with free, complementary nucleotides. Another enzyme bonds the sugar and phosphate molecules together to form the backbone of the new strand. Yet another enzyme proofreads the new strands to ensure accuracy and to make corrections if required.

DNA replication occurs fairly quickly; as many as 4000 nucleotides per second are replicated. The replication of DNA is essential for cell reproduction to occur. Cell reproduction must occur so that growth and repair of body tissues are possible.

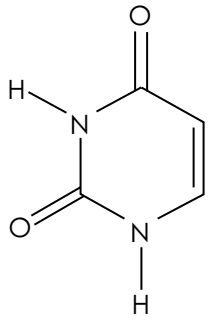
RNA Structure and Function

Before you learn about transcription and translation, the other two processes discussed in this lesson, it is important to recognize ribonucleic acid (RNA), the other nucleic acid molecule essential to those processes. Like DNA, RNA is a molecule that consists of a chain of smaller molecules known as *nucleotides*.

There are some important structural and functional differences between DNA and RNA:

- The sugar present in RNA is ribose instead of deoxyribose, which is present in DNA.
- RNA contains uracil instead of thymine. Like thymine, uracil is a pyrimidine; therefore, it possesses one ring. It bonds with adenine (A) in an RNA molecule. Uracil (U) possesses the chemical structure shown in Figure 2.9.

Figure 2.9 ***Uracil***



- RNA is a single-stranded molecule. DNA is like a twisted ladder, while RNA is like a half-ladder made of a chain of nucleotides.
- DNA stays in the nucleus of the cell, whereas RNA moves out of the nucleus into the cytoplasm of the cell. *Transcription* is the process of making RNA, using DNA as a template; transcription occurs in the nucleus of the cell. However, *translation* is the process of using RNA to build proteins; translation occurs in the cytoplasm of the cell. A cellular structure called a *ribosome* is used to carry out translation.
- There are three types of RNA molecules, all of which are involved in translation:
  - messenger RNA (mRNA)
  - transfer RNA (tRNA)
  - ribosomal RNA (rRNA)

Transcription

DNA is located inside the nucleus of the cell. It instructs the cell by controlling the types of proteins that the cell produces. The types of proteins produced determine the structural and functional traits that the cell possesses.

So how does the information carried in the DNA molecule reach the site of protein synthesis, which is located in the cytoplasm? The answer lies in the RNA molecule. One type of RNA, mRNA, is synthesized in the cell nucleus and then travels out of the nucleus into the cytoplasm. It moves to where *ribosomes* are located. You have learned in previous science courses that ribosomes are the sites of protein synthesis. Ribosomes are cellular components that use the information stored in mRNA to make proteins.

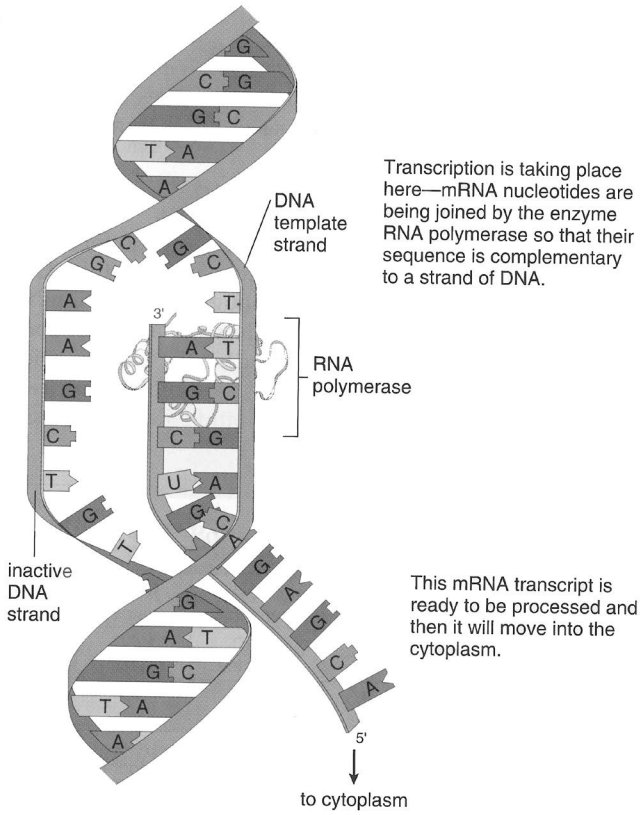
During the process of transcription, DNA is used as a *template* to make RNA. The DNA molecule unzips, exposing its organic bases. Complementary RNA nucleotides in the cell nucleus move into position. Recall that RNA possesses uracil instead of thymine. So, these base pairings exist as RNA is synthesized:

(DNA)		(RNA)
	T ↔ A	
	A ↔ U	
	G ↔ C	
	C ↔ G	

After RNA nucleotides have paired up correctly with their complementary nucleotides in the DNA chain, they bond to each other, forming a single strand. The temporary bonds that the single strand had with the DNA template break, and the mRNA strand moves away from the DNA template. The DNA double helix is restored as the base pairings forming the rungs of the ladder are reformed.

The process of transcription is illustrated in Figure 2.10.

Figure 2.10 **The Process of Transcription**



Source: Mader, Sylvia S. *Inquiry into Life*. 11th ed. New York, NY: McGraw-Hill, Higher Education, 2006. 491.

As a result of transcription, the permanent code stored in the DNA double helix remains in the nucleus, while its messenger, mRNA, carries the code in a single-stranded format out into the cytoplasm. The cell's nuclear genetic information, DNA, is used as a template to make a messenger molecule that is able to move into the cytoplasm of the cell. The cytoplasm is where ribosomes are found; it is where translation occurs and proteins are made.

Translation

The mRNA that is produced during the process of transcription in the cell nucleus moves out of the nucleus and into the cytoplasm of the cell. The cytoplasm is where *ribosomes* are located. Ribosomes are the cell organelles responsible for protein synthesis. The use of mRNA to manufacture proteins is the process of *translation*. Recall that ribosomes are partially made of rRNA. The mRNA strand connects to the ribosome. The ribosome is a structure that temporarily brings together the mRNA strand and tRNA molecules in the cytoplasm. That is important because tRNA molecules carry amino acids.

Each tRNA molecule in the cytoplasm has two specific functional sites. One end of the molecule is attached to one of the 20 amino acid molecules that are found in nature, and the other end is made up of a triplet of nitrogen-containing bases, the same type of bases found in mRNA. Since the organic bases in RNA (U, A, C, and G) match up with one another in predictable ways, each triplet of bases on the tRNA molecule will match up with a triplet of bases on the mRNA strand. Recall that the sequence of bases on the mRNA strand carries information from the DNA in the cell's nucleus. In the cytoplasm, the mRNA sequence determines which tRNA molecules will be temporarily brought into position by the ribosome. Recall that each tRNA molecule carries a predictable amino acid into position along the mRNA strand.

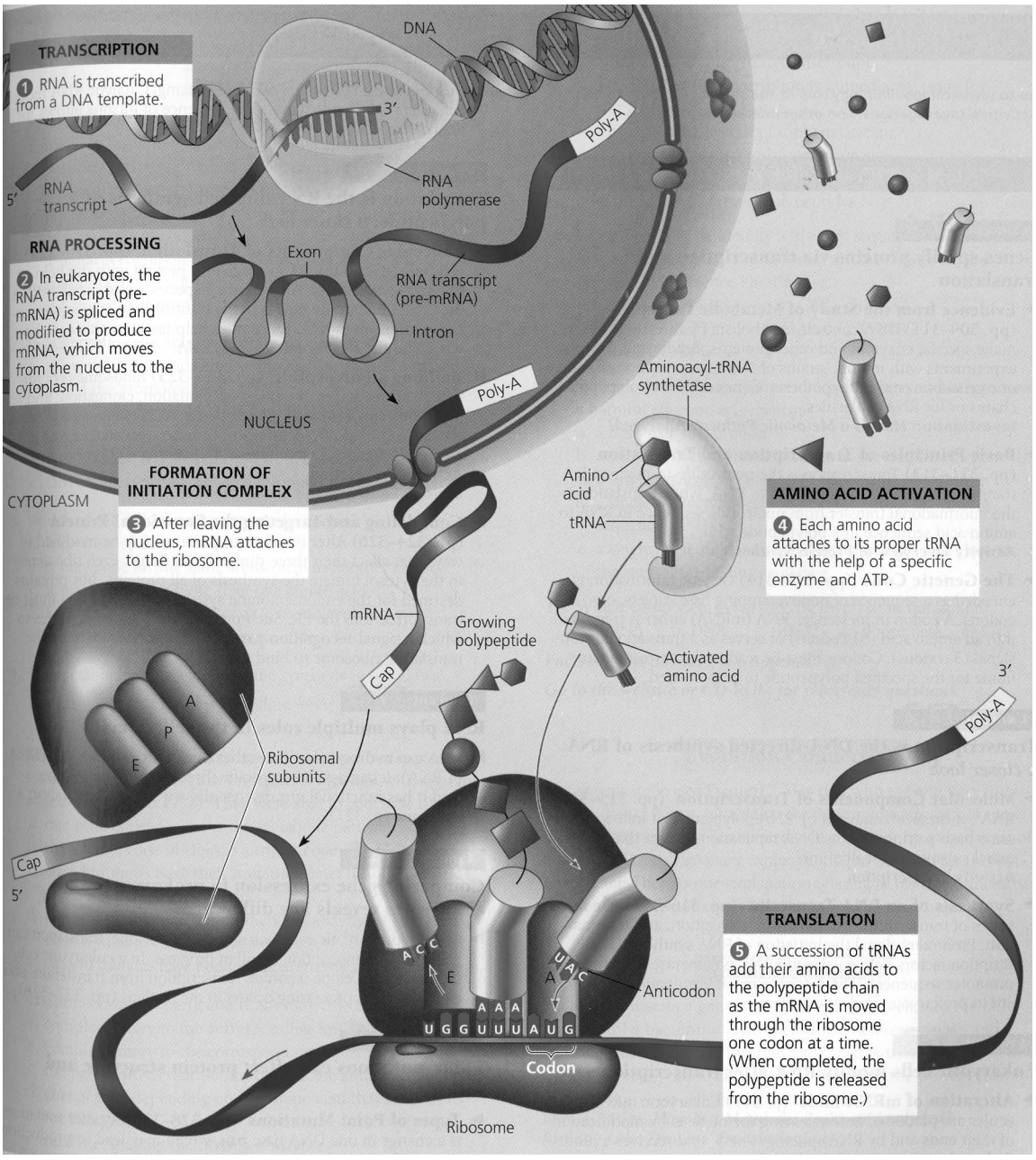
Each triplet of bases on the mRNA strand is called a *codon*. Each triplet of bases on each tRNA molecule is called an *anticodon*. If the codon is C–G–A, the matching anticodon is G–C–U. The specific pairings of bases makes the process predictable. The amazing part of this process is that tRNA molecules carry amino acids, the building blocks of proteins. Each anticodon indicates that a particular amino acid is attached to that tRNA molecule.

So, you can see that the sequence of bases in the DNA is used to build a strand of mRNA with a particular sequence of bases, which travels into the cytoplasm. There, specific tRNA molecules move into position, as anticodons match codons. As a result, a particular sequence of amino acids is created. When peptide bonds form between those amino acids, a protein molecule is manufactured. The genotype of a particular cell is determined

by the sequence of bases in its DNA. The phenotype of a particular cell is a structural or functional trait that results because of the presence of particular protein molecules. So, genotype determines phenotype—the connection is made between the presence of a particular gene and the existence of a particular trait.

Consider the diagram of transcription and translation shown in Figure 2.11.

Figure 2.11 **Transcription and Translation**



Source: Campbell, Neil A., and Jane B. Reece. *Biology*. 7th ed. San Francisco, CA: Pearson Education, Benjamin Cummings, 2005. 331.

Note that there are "stop" codons that tell the ribosome that the protein is complete. In the end, a sequence of bases on a nucleic acid chain is translated into a sequence of amino acids on a protein chain. The nucleic acid molecule is the "recipe" and the protein is the finished product.

The genetic code is connected to specific protein sequences according to the mRNA codon chart shown in Table 2.1. This genetic code is said to be universal because the pairings shown in this chart are valid for all living organisms, regardless of their complexity.

Table 2.1 **mRNA Codon Chart**

First Base	Second Base				Third Base
	U	C	A	G	
U	UUU phenylalanine	UCU serine	UAU tyrosine	UGU cysteine	U
	UUC phenylalanine	UCC serine	UAC tyrosine	UGC cysteine	C
	UUA leucine	UCA serine	UAA *stop*	UGA *stop*	A
	UUG leucine	UCG serine	UAG *stop*	UGG tryptophan	G
C	CUU leucine	CCU proline	CAU histidine	CGU arginine	U
	CUC leucine	CCC proline	CAC histidine	CGC arginine	C
	CUA leucine	CCA proline	CAA glutamine	CGA arginine	A
	CUG leucine	CCG proline	CAG glutamine	CGG arginine	G
A	AUU isoleucine	ACU threonine	AAU asparagine	AGU serine	U
	AUC isoleucine	ACC threonine	AAC asparagine	AGC serine	C
	AUA isoleucine	ACA threonine	AAA lysine	AGA arginine	A
	AUG *(start)* methionine	ACG threonine	AAG lysine	AGG arginine	G
G	GUU valine	GCU alanine	GAU aspartate	GGU glycine	U
	GUC valine	GCC alanine	GAC aspartate	GGC glycine	C
	GUA valine	GCA alanine	GAA glutamate	GGA glycine	A
	GUG valine	GCG alanine	GAG glutamate	GGG glycine	G

Source: Mader, Sylvia S. *Inquiry into Life*. 11th ed. New York, NY: McGraw-Hill, Higher Education, 2006. 492.

The chart above illustrates how codons (mRNA) code for specific amino acids. A similar chart could be made to show how anticodons (tRNA) code for specific amino acids.

There are 20 amino acids found in nature. Notice that one amino acid is often coded for by more than one codon. That is the case because when four possible bases are combined in groups of three, there are 64 possible codons. Since there are 64 codons and 20 amino acids, each amino acid is coded for by more than one codon. Notice that each codon, however, codes for only one amino acid.

Consider the process from DNA to protein in the following example:

DNA sequence that is used as a template:	T – A – G – C – G – A – T – C – G
mRNA sequence that is transcribed:	A – U – C – G – C – U – A – G – C
tRNA anticodons that match the mRNA codons:	U – A – G C – G – A U – C – G
Amino acid sequence that results:	isoleucine – alanine – serine

Each protein molecule manufactured by living cells has a very particular length, three-dimensional structure, and amino acid sequence. Proteins are very specific in terms of the functions they serve in the cell. Proteins are the compounds that determine the structure and function of each cell and its parts. The particular proteins that are manufactured by each cell depend on the genetic code carried in its nucleus.

In the next lesson, you will learn about how changes in the sequence of bases in DNA (mutations) can occur and how they can affect the structure and function of the cell.

Learning Activity 2.3: Replication, Transcription, and Translation

This learning activity will give you an opportunity to review what you have learned about replication, transcription, and translation. Please record your responses in your notebook.

1. Compare the three processes—replication, transcription, and translation—in terms of
   a) the location where the process occurs in the cell
   b) the end product of the process in the cell

	Location	End Product
Replication		
Transcription		
Translation		

2. Compare the three molecules—DNA, mRNA, and tRNA—in terms of
   a) their location in the cell
   b) organic bases present
   c) their overall structure
   d) the sugar molecule present in each nucleotide
   e) their function in the cell with respect to protein synthesis

	DNA	mRNA	tRNA
Location			
Bases			
Structure			
Sugar			
Function			

3. Explain, as clearly as you can, how genotype determines phenotype.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 2.3. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about the fascinating connection that exists between genotype and phenotype. Specifically, you have learned how the sequence of bases in DNA, the genetic code, determines which proteins are produced. You have made the connection between the proteins produced and the structural and functional traits possessed by the cell. In Lesson 3, you will learn about how errors in the genetic code can affect the cell.

Assignment 2.3: Replication, Transcription, and Translation (35 marks)

This assignment will give you an opportunity to demonstrate your understanding of the processes of replication, transcription, and translation. Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 2.

1. Fill in the chart below. Use the mRNA Codon Chart from Table 2.1 in this lesson to translate the genetic code. *(15 marks)*

DNA Template	mRNA Codon	tRNA Anticodon	Amino Acid
		GCG	
CAT			
	AAC		
			tryptophan
AGC			

2. Write a paragraph describing how transcription, translation, and replication work, and how they are related. Include each of the following terms at least once in your paragraph. *(15 marks)*

amino acid	genetic code	replication
anticodon	mRNA	ribosome
codon	nucleus	transcription
cytoplasm	phenotype	translation
DNA	protein	tRNA

(continued)

3. How can the genes that a cell possesses determine how the cell acts and how it is made? *(5 marks)*

Lesson 4: Genetic Mutations

Lesson Focus

In this lesson, you will

- ❑ relate the consequences of gene mutation to the final protein product

  Examples: point mutation in sickle-cell anemia, frameshift mutation in β-thalassemia . . .

- ❑ discuss implications of gene mutation for genetic variation

  Include: sources of new alleles

Introduction

So far in Module 2, you have learned about the structure and function of the genetic information contained in the nucleus of the cell. You have studied DNA and RNA, the two nucleic acids involved in this study of genetics. You have also learned about mRNA and tRNA, two molecules that help to accomplish protein synthesis in the cytoplasm of the cell. Now, in this lesson, you will learn about how errors in the genetic code, mutations, can affect the structure and function of the cell by affecting the proteins that the cell is able to manufacture.

The Mechanics of Genetic Mutations

Mutations are changes made to the nucleotide sequence of the genetic molecules of a cell. Mutations may be caused by copying errors during the process of replication before a cell divides by mitosis. They may also be caused by various chemicals called *mutagens*. Some forms of radiation, such as ultraviolet radiation, can cause mutations to occur. Genetic mutations can also be caused by some viruses. In a multicellular organism, mutations that occur in reproductive cells such as egg and sperm are called *germ-line mutations*, and those that occur in non-reproductive cells are called *somatic mutations*. Germ-line mutations are passed on to offspring, whereas somatic mutations are not.

Genetic mutations can occur in a number of ways. In general, a gene is a portion of a DNA chain of nucleotides that codes for a particular trait. When the sequence of those nucleotides is altered, a mutation has occurred. Some mutations have little or no effect on the cell or organism, whereas other mutations are harmful or even lethal to the cell or organism.

You will look at two general types of mutations, those that involve small changes in the nucleotide sequence and those that involve large changes in the nucleotide sequence. The next section of this lesson focuses on the various effects that mutations can have on cells and organisms carrying them.

Small-Scale Mutations

Small-scale mutations affect one or a few nucleotides in the cell's DNA. Three types of small-scale mutations are discussed below: point mutations, insertions, and deletions.

- **Point mutations:** When a point mutation occurs, a purine is substituted for a purine (A ↔ G) or a pyrimidine is substituted for a pyrimidine (T ↔ C). Much less commonly, a purine is substituted for a pyrimidine, or vice versa. This type of error usually occurs during replication. Point mutations, although affecting only a small portion of the DNA strand, can have profound effects on the cell or organism. When a point mutation occurs but the amino acid coded for by that base triplet remains the same, it is referred to as a *silent mutation* because the same protein is produced. A *missense mutation* occurs when a different amino acid is coded for; as a result, the protein produced is different from the one needed by the cell. Finally, a *nonsense mutation* occurs when the coded message says "stop" and the amino acid chain is cut off too early.

  An example of a point mutation that has a profound effect on the cell occurs in the case of *sickle-cell anemia*. A thymine (T) base is substituted for an adenine (A) base at the 17th nucleotide of the gene for part of the hemoglobin molecule. As a result, the DNA triplet GAG (for glutamic acid, one of the 20 amino acids) becomes GTG (for valine, another of the amino acids). This altered hemoglobin molecule does not function as well as the unaltered molecule. Hemoglobin is the compound in red blood cells that attaches to and carries oxygen molecules in the blood. A change in the shape of the red blood cells occurs when the altered hemoglobin molecules are produced. The new shape is sickle-shaped instead of circular, as shown in Figure 2.12. These sickle-shaped cells cannot carry oxygen as efficiently.

Figure 2.12 **Sickle-Shaped Cells**

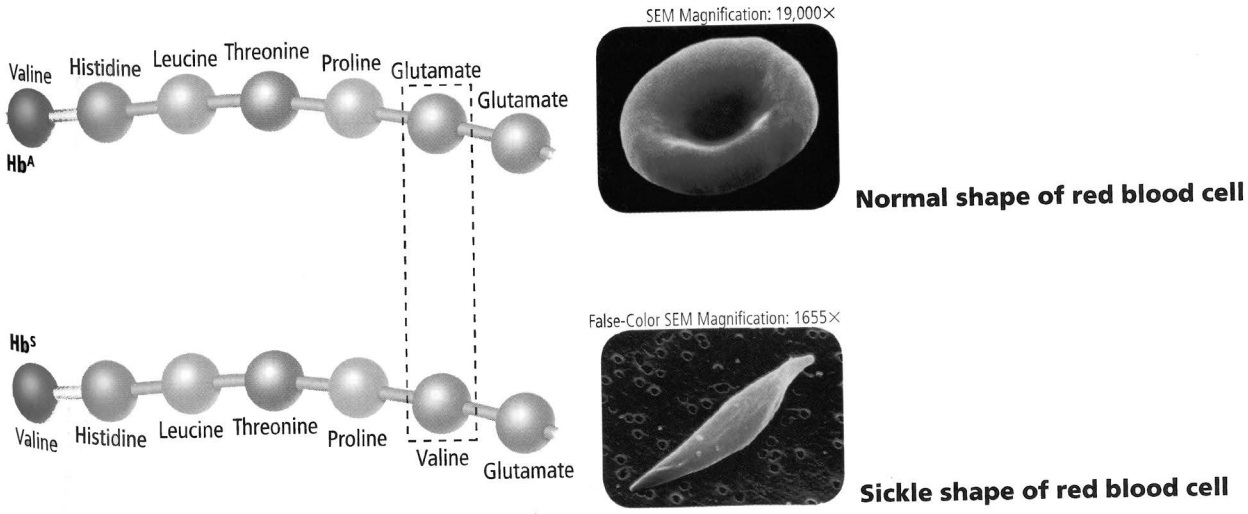


Photo credit: Jackie Lewin, Royal Free Hospital/Photo Researchers

Source: Biggs, Alton, et al. *Glencoe Science Biology*. Columbus, OH: Glencoe/McGraw-Hill, 2009. 347.

It is noteworthy that the sickle-cell anemia gene also gives a person carrying it an increased resistance to malaria, a life-threatening disease in many parts of the world. You will return to this example in the next module when you look at why genetic mutations persist in populations if the abnormalities they cause are detrimental to the individual organism. In the case of the sickle-cell anemia gene, it is believed that the gene has persisted because it results in a greater resistance to a different and serious disease.

- **Insertions:** Insertions add one or more nucleotides into the DNA sequence of the cell. These mutations cause a *frameshift* to occur because each of the triplets following the inserted nucleotide(s) is altered. To see this clearly, consider the following example in which a cytosine nucleotide is randomly inserted:

Original DNA strand:	T – A – T	T – C – G	G – C – A	A – T – C	C – G – A
Altered DNA strand:	T – A – T	T – C – **C**	G – G – C	A – A – T	C – C – G

You can see that, since the nucleotides "make sense" in triplets, an insertion of just one nucleotide has a profound effect on the protein that is produced.

- **Deletions:** Deletions occur when one or more nucleotides are deleted from a DNA chain. These mutations, like insertions, can cause a *frameshift* to occur. An example of this type of mutation occurs in patients suffering from β-thalessemia. Consider the original chain and the altered chain that results when two adenine nucleotides are deleted from the sequence:

Original DNA strand:	G – A – G	G – A – G	**A** – **A** – G	T – C – T	G – C – C
Altered DNA strand:	G – A – G	G – A – G	G – T – C	T – G – C	C – G – T

  The missense mutation from the point of deletion creates an early polypeptide chain termination. The hemoglobin molecule is short and defective. As a result, the red blood cells are smaller than normal and their oxygen-carrying capacity is reduced.

Large-Scale Mutations

Large-scale mutations affect a greater number of mutations. They are less likely to be silent, since they affect so many nucleotides. Four types of large-scale mutations are discussed below:

- **Deletions:** In some cases, large chromosomal regions are deleted; this leads to the loss of the genes carried within those regions. These deletions are not always seriously harmful to the cell, but they often are.
- **Amplifications:** Sometimes, genes are duplicated; multiple copies of the chromosomal regions affected result from this error. Multiple copies of affected genes lead to the over-production of the proteins coded for by those genes.
- **Translocations:** These mutations occur when two non-homologous chromosomes exchange segments. In the cell nucleus, chromosomes are threadlike and very thin during much of the cell cycle. During these times especially, non-homologous chromosomes may come close enough to each other to touch; when this occurs, the DNA strands may "trade pieces" at the point of overlap of the strands.
- **Inversions:** When these mutations occur, a piece of the DNA strand is reversed; as a result, the triplets are read backwards. Consequently, different amino acids are arranged into the protein that is produced.

So far, you have looked at some of the types of mutations in terms of their structural nature. You will now also consider the functional effects that mutations can have on the cell.

The Effects of Genetic Mutations

Genetic mutations can affect the functioning of the cell in a number of ways. In this lesson, you will learn about the following six types of effects that genetic mutations can have on the cell or organism:

- **Loss-of-function mutations:** When these mutations occur, they result in a protein product that has little or no normal function in the cell.
- **Gain-of-function mutations:** Although these mutations may at first seem beneficial, a cell does not normally need the ability to perform additional functions. The function gained may not be beneficial to the cell.
- **Dominant negative mutations:** These mutations cause an altered gene product that antagonizes the normal gene product. As a result, even if the multicellular organism possesses normal cells with normal genes that produce the normal protein product, other cells may contain the mutated genes that produce the abnormal protein product. The abnormal gene product acts antagonistically to the normal gene product.
- **Lethal mutations:** These mutations are so damaging that the cell or organism dies as a result of its occurrence.
- **Morphological mutations:** These mutations cause a change in the outward appearance of the cell or organism. An example of such a change could involve the colour or shape of the organism.
- **Biochemical mutations:** These mutations affect the production of enzymes. Recall that enzymes are biological catalysts that affect the chemical reactions that occur in the cell. These biochemical changes may have very little effect on the cell, or they may be profound in their effect.

These six types of effects are not mutually exclusive; that is, a particular mutation may have more than one type of effect.

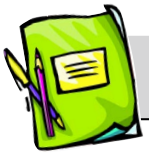
Adaptive Aspects of Mutations

As you have already learned, some mutations have no effect on the cell or organism. Negative as well as positive effects can, however, range widely. Mutations are not always "bad." In fact, the source of genetic change in the biological world is mutation. Natural selection postulates that beneficial mutations are those that increase the reproductive success of the organism. As a result, beneficial mutations are more often passed on to offspring and, therefore, become more common in the population. Conversely, detrimental mutations decrease the reproductive success of the organism. As a result, these mutations are not passed on as often to offspring and, therefore, become less common in the population.

The reproductive success of an organism depends on a number of factors, some of which are environmental. If the environment of an organism changes, the traits that lead to reproductive success may also change. In other words, organisms that had been well adapted to the original environmental conditions are not as well adapted when the conditions change. Environmental conditions may be the result of a wide variety of ecological factors, such as competitors, predators, prey, weather, human interference, and so on.

The important point here is that genetic mutations introduce genetic variation into populations of organisms. Genetic mutations sometimes result in new alleles being formed, which lead to new phenotypes. Those phenotypes may be adaptive or maladaptive, depending on environmental pressures on the organism. Over time, a group of organisms possessing a new phenotype may become isolated from the larger population. Mutations will continue to occur in both groups; however, since they are isolated from one another, the mutations that occur will probably be different mutations. As a result, over time, the two groups may become so dissimilar genetically from one another that they are no longer able to interbreed. This type of reasoning shows how new species can evolve over time.

Evolutionary biology is a fascinating branch of biology, and you have only touched on it here. Mutations create genetic variation. Genetic variation enables some organisms to reproduce more successfully than other organisms. This leads to genetic change over time. That is evolution by natural selection in a nutshell.



Learning Activity 2.4: Genetic Mutations

Review what you have learned about genetic mutations by responding to the following questions. Record your responses in your notebook.

1. The DNA sequence of a gene can be compared to a sentence made up entirely of three-letter words and without spaces. An example follows:

   thesunwashotbuttheoldmandidnotgethishat

   This sentence, considered as triplets of letters, reads as follows:

   the sun was hot but the old man did not get his hat

   a) Mimic an **insertion mutation** by inserting a random letter into the sentence. How does this insertion affect the sentence?

   b) Mimic a **deletion mutation** by deleting a random letter from the sentence. How does this affect the sentence?

   c) Mimic a **point mutation** by substituting a random letter into the sentence. How does this affect the sentence?

   d) Mimic an **inversion mutation** by reversing a word in the sentence. How does this affect the sentence?

2. Explain the following statement: "Genetic mutations are the raw material that natural selection acts upon."

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 2.4. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about genetic mutations—changes in the genetic code of a cell. You have learned about some ways in which mutations can occur and about some ways in which mutations can affect a cell or an organism. In addition, you have learned about how genetic mutations result in genetic variation in the natural world, and that mutations are not always detrimental.

In the next lesson, you will learn about how genetic knowledge has been applied in many different areas related to human health and welfare. As we learn more about the broad field of genetics, we also gain the ability to put that knowledge to use in applied fields of study. As you know, these applications sometimes have ethical implications that must be considered. Controversy results when scientific knowledge and abilities are not met with sufficiently adequate or timely ethical consideration.

Assignment 2.4: Genetic Mutations (36 marks)

Read all the instructions for this assignment before you begin your work. Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 2.

In this assignment, you will simulate the mechanism of protein synthesis and determine the traits of a fictitious plant. You will consider eight genes that are responsible for eight traits that the plant possesses. Use Table 2.1: mRNA Codon Chart (in Lesson 3, Module 2) to translate mRNA codons into amino acids. Use Table 2.2 below to translate the amino acid sequence into traits. Complete the chart on the next page, and then answer the questions that follow.

Table 2.2 **mRNA Codon Chart**

Amino Acid Sequence	Trait
Serine – Arginine	Pink flowers
Serine – Histidine	Yellow flowers
Glutamic Acid – Alanine – Histidine	Thorns
Leucine – Alanine – Histidine	No thorns
Histidine – Cysteine – Proline	Simple leaves
Histidine – Leucine – Proline	Compound leaves
Valine – Glycine – Alanine	Fibrous roots
Valine – Glutamic Acid – Alanine	Taproot
Leucine – Valine - Isoleucine	Woody stem
Leucine – Methionine – Proline	Non-woody stem
Threonine – Glycine – Asparagine	Purple fruit
Threonine – Glutamic Acid – Alanine	Green fruit
Methionine – Stop	Wind-pollinated
Leucine – Stop	Insect-pollinated
Aspartic Acid – Glycine	Leaves with serrated edges
Aspartic Acid – Leucine	Leaves with smooth edges
Glycine – Isoleucine – Proline	Poisonous
Valine – Isoleucine	Waxy cuticle on leaves
Phenylalanine – Arginine	Insectivorous
Lysine – Serine – Asparagine	Conspicuous odour

(continued)

Assignment 2.4: Genetic Mutations (continued)

1. Specify the mRNA, amino acids, and traits for eight genes of a fictitious plant, using the mRNA Codon Charts provided. *(24 marks—3 marks for each gene)*

Gene 1	**Gene 2**
DNA: TGC CCA TTG	DNA: GTA AAC GGA
mRNA: _____	mRNA: _____
Amino acids: _____	Amino acids: _____
Trait: _____	Trait: _____
Gene 3	**Gene 4**
DNA: AGG GCG	DNA: CCC TAT GGT
mRNA: _____	mRNA: _____
Amino acids: _____	Amino acids: _____
Trait: _____	Trait: _____
Gene 5	**Gene 6**
DNA: GAG CAT TAG	DNA: AAT CGG GTA
mRNA: _____	mRNA: _____
Amino acids: _____	Amino acids: _____
Trait: _____	Trait: _____
Gene 7	**Gene 8**
DNA: TTC AGT TTA	DNA: TAC ATT
mRNA: _____	mRNA: _____
Amino acids: _____	Amino acids: _____
Trait: _____	Trait: _____

(continued)

Assignment 2.4: Genetic Mutations (continued)

2. Mutations are changes in the nucleotide sequence in the DNA molecule. Explain how each of the following changes would affect the amino acid sequence that results from translation. *(6 marks—2 marks for each question)*

   a) How would the addition of a single nucleotide affect the amino acid sequence?

   b) How would the deletion of a single nucleotide affect the amino acid sequence?

(continued)

c) How would the substitution of one nucleotide for another nucleotide affect the amino acid sequence?

3. Name one specific mutation in the DNA of the fictitious plant that would result in yellow flowers instead of pink flowers. There may be more than one mutation that you could name. *(3 marks)*

4. If the sequence of amino acids for a particular trait were known, how could the DNA sequence for that gene be determined? *(3 marks)*

Lesson 5: Applications of Genetic Knowledge

Lesson Focus

In this lesson, you will

- ❑ investigate an issue related to the application of gene technology in bioresources

  Include: understanding the technology/processes involved, economic implications, a variety of perspectives, and personal/societal/global implications

- ❑ investigate an issue related to the application of gene technology in humans

  Include: understanding the technology/processes involved, ethical and legal implications, a variety of perspectives, and personal/societal/global implications

Introduction

Ongoing research in the field of gene technology has provided both great promise and possible threat for the future. The knowledge base and its technological applications are rapidly advancing and changing. However, many ethical and practical issues surrounding the use of gene technology are hotly debated today. In this lesson, you will learn about how genetic knowledge has been applied in the areas of biological resource management and human health and welfare.

Biological Resource Management

Our understanding of genetics has been applied to many biological projects. In this lesson, you will concentrate on three particular applications of genetic knowledge: genetically modified organisms, the cloning of animals, including pets, and the patenting of transgenic organisms.

Genetically Modified Organisms

Sometimes, a genetically modified organism (GMO) is referred to as a genetically engineered organism (GEO); for the purposes of this course, these terms are interchangeable. A *GMO* is an organism whose genetic material has been changed using genetic engineering techniques. These genetic engineering techniques are commonly referred to as *recombinant DNA technology*. In general, DNA material from different sources is combined, thereby creating a new gene. When the new DNA is transferred back into a living organism, the machinery of its cells decodes the new gene and the expression of its traits is displayed. This organism is said to be *transgenic*, because it possesses DNA that came from another organism.

Genetically Modified Animals

Various organisms have been used in genetic experimentation involving transgenic mice, fish, and plants, and many types of microscopic species. Various animals are used in experimental studies that look at genes whose functions are unknown. The fruit fly, *Drosophila*, is often used in experiments aimed at understanding the effects of genetic changes on development; fruit flies are easily cultured and their genetic material is much simpler than that of animals that are genetically more complex. Transgenic mice are used in a variety of experiments; typically, they are used in studies of cellular and tissue-specific responses to disease.

Genetically Modified Plants

The development of a wide variety of transgenic plants has had many applications in agriculture. Genetically modified (GM) foods were first available on the market in the early 1990s. In fact, the first GM food crop was the tomato, which was released into the market in 1994. This GM tomato was more resistant to rotting. Traits such as resistance to pests, herbicides, or certain environmental conditions are commonly targeted by such experimentation. The nutritional value of some foods has been improved through the use of genetic engineering technology. An example of such a development is golden rice, which contains a higher level of vitamin A than conventional unaltered rice. The genes used in the production of this GM rice were two daffodil genes and one gene from a bacterium. Other GM plants are constantly being introduced into agriculture. The most common GM foods are produced by using soybeans, corn, canola, and cotton.

An example of a GM plant is Bt corn. There are actually several genetic variations of this plant; all of them, however, have increased resistance to insect pests, such as the European corn borer. This resistance is the result of a gene that has been incorporated into the corn plant's DNA. The gene is taken from a bacterium, *Bacillus thuringiensis* (*Bt*), which is a pathogen that attacks the corn borer. The corn, in effect, has acquired the ability to attack its attacker, the insect pest. The history of Bt corn actually dates back to the 1930s in France, where corn crops were sprayed with a solution containing the Bt bacteria known to attack the corn borer and a number of other insect pests. No toxic effects of this practice on humans have ever been detected. This practice has always had limited success, however, because the bacteria do not survive very long on the surface of the plant. Furthermore, some pests, including the corn borer, do not attack as adults on the plant surfaces, but instead as larvae deep within the stem. The GM corn attacks insect pests wherever they are feeding in the plant body.

Ethical Considerations

Around the world, a great deal of controversy exists regarding the use of GMOs. Some critics warn that genetic modifications may have unforeseen consequences in the future. For example, strains of corn that are resistant to certain insect pests inevitably cross with wild strains of corn; as a result, it is feared by some that the genetic diversity of corn may be altered with unknown effects. Some scientists fear that GMOs, when released into the natural world, are uncontrollable and may affect natural ecosystems in ways that cannot be foreseen. For example, if plants are developed that are toxic to insect pests, then animals, such as birds that depend on insects for food, will suffer.

On the other hand, proponents of the use of GMOs point to areas of the world widely affected by drought and starvation, such as parts of Africa. If GMOs could be developed that could survive the harsh environmental conditions found there, many people could avoid starvation. The production of the previously mentioned golden rice variety could mean that many people who would die or go blind because of a vitamin A deficiency could be saved.

Cloning Animals

Imagine that a treasured pet dies. Is it possible that somehow that pet could be cloned for its owner? Could the person receive a genetic twin to the original pet after its death? Does this sound like science fiction to you?

Cloning Pets

In 2001, the first cat was experimentally cloned and referred to as copycat or CC. Little Nicky was the first commercially cloned cat. In December 2004, a woman paid $50,000 (US) for Little Nicky, the clone of her deceased 17-year-old cat, Nicky. The company responsible for this feat was Genetic Savings and Clone, which was founded in 2000 by Lou Hawthorne, whose family dog, Missy, had died. His decision to clone Missy was referred to as the Missyplicity project, which was funded by Hawthorne's friend, John Sperling, a wealthy businessman. The project lasted for over three years and cost approximately $4 million (US).

The company operated a pet bank where pet owners could deposit tissue samples from their pets for later use in cloning. The business closed in 2006 due to technological obstacles that prevented its economic success. Until the pet-cloning process can become more of an assembly line process, it will probably remain extremely expensive. For one thing, the cost paid for Little Nicky is far too high for most people to afford.

Dolly

In 1984, Steen Willadsen, a Danish embryologist, cloned a lamb from a developing sheep embryo cell. The process was repeated by many other scientists who cloned a variety of animals from embryonic cells. It is important to note that the DNA used in this cloning process was not adult DNA, as it was in the case of Genetic Savings and Clone's endeavours.

In 1996, a ewe named Dolly was the first animal to be successfully cloned from an adult somatic cell. (For a picture of Dolly as a lamb, see Figure 2.13.) The work was done at the Roslin Institute in Scotland. The somatic cell from which Dolly developed was taken from the mammary gland of another ewe; that very specialized somatic cell possessed the genetic information necessary for the production of an entire individual ewe. The nucleus from the adult cell was transferred into an unfertilized developing egg cell that had its nucleus removed. When that initial cell had divided a number of times, it was implanted into a surrogate mother ewe.

Dolly was the only lamb to survive to adulthood from 277 cloning attempts by the research team. Dolly lived to have six lambs. At the age of five, Dolly developed crippling arthritis. At the age of six, she suffered from a progressive lung disease and was euthanized. Dolly died at a relatively young age, and some attribute this early death to the fact that the ewe from which the initial DNA was taken in 1996 was herself six years of age.

Figure 2.13 **Dolly**

Photo credit: Photograph courtesy of the Roslin Institute.

Source: Audesirk, Teresa, Gerald Audesirk, and Bruce E. Byers. *Biology: Life on Earth*. 6th ed. Upper Saddle River, NJ: Prentice-Hall, Inc., 2002. 193.

Other Animals

Following the success of Dolly's birth, a number of other animals, including horses, cows, goats, pigs, rats, mice, rabbits, and mules, have also been successfully cloned. Primates are absent from that list. In 1996, a dog named Snuppy was cloned successfully in South Korea; dogs are considered more difficult than cats to clone because of their complex reproductive biology. Some researchers see possibilities for this technology to be applied to the preservation of endangered species. Others argue that the cost of cloning is still too high to make it a viable technique. Cloning is not a viable technology for human patients; our understanding of genetics is far too limited for human cloning to be considered possible at the present time.

Patenting Transgenic Organisms

Currently, a number of countries protect patent claims for transgenic plants and animals. These transgenic organisms possess DNA from another species, in addition to their own DNA. The transgenic genetic material is introduced into the cells of the recipient organism and, in situations that are successful, is incorporated into the genetic material of that recipient. The transgenic organism then starts to produce the proteins coded for by the DNA material that has been introduced, in addition to producing its own protein products. An issue related to this technology, however, is that when transgenic organisms are "created" by the corporate world, they are sometimes patented as inventions; these organisms, which are useful in the scientific community, are often too expensive to use because they are patented.

OncoMouse®

In 1988, Harvard University geneticist Philip Leder and Timothy Stewart of the University of California were issued a patent by the United States Patent and Trademark Office (USPTO) for their development of OncoMouse. OncoMouse is a transgenic mouse that possesses an introduced gene sequence that makes the mouse susceptible to cancer. The OncoMouse was seen as the ideal test animal for toxicology research and new medical technologies to treat cancer.

In 1989, DuPont and Harvard University signed a legal document of mutual understanding that gave the company exclusive rights to license OncoMouse and to control its use by researchers. DuPont imposed very strict licensing agreements on the use of related OncoMouse technologies. As a result, DuPont charged high fees to other companies and university scientists who were interested in using OncoMouse to study cancer. This is seen by many as a serious impediment to cancer research.

This perspective is largely due to the fact that, when a patent is issued, the company obtaining the patent typically tries to make it as broad in scope as possible; this protects the company from having other companies or researchers build on its research and obtaining patents themselves. But the problem is that broad patents stifle research; early-stage research is an innovative, creative process stimulated by the involvement of many scientists. A broad patent shuts down that process when it restricts the use of the transgenic organism in further research by other scientists.

Ethical Considerations

Should transgenic organisms be patented? This is a complicated question because it is tied to how an individual sees the assertion that transgenic organisms are "created" or "invented" by the group applying for the patent. In 1980, the United States Supreme Court ruled that an oil-digesting bacterium could be patented. The legal decision was based on the viewpoint that the fact that the invention was alive was without legal significance. In 1987, a decision was made by USPTO to patent the first multicellular organism, an oyster. Canada adopted a similar set of guidelines regarding the patenting of transgenic organisms in 1998.

Clearly, there are two areas of controversy regarding transgenic organisms. The first deals with whether or not the patenting of living organisms is ethical. The second deals with whether or not broad patents should be issued to corporations that develop transgenic organisms, thus making the use of those organisms by the broader scientific community too expensive. Historically, one of the primary functions of universities has been to disseminate knowledge; as a result of broad patenting practices, university researchers are more likely to keep their discoveries "secret" so that they are not "stolen" by the corporate world. A large group of researchers believes that genes and organisms should not be patented, so that they could be used by researchers all over the world in their diverse disciplines related to genetics.

Human Health and Welfare

The technology related to genetic research has had a great diversity of applications in the area of human health and welfare. Examples of such applications continue to multiply as our knowledge and understanding of genetics continue to grow. Only a few examples are discussed in this course.

Stem Cell Research

Stem cells were initially identified and proved to exist in 1961 by two Canadian scientists, Jim Till and Ernest McCulloch. Stem cells are flexible cells in terms of what they will become in the developing organism. They are able to reproduce themselves continually, while still keeping the ability to give rise to more specialized types of cells. Stem cells can be found in human embryos, as well as in children and adults. In fact, adult stem cells can be found in many body tissues, including the blood, brain, skin, intestine, and muscle. Until recently, it was believed that adult stem cells were far less flexible than embryonic stem cells. Continuing research will clarify the extent to which this is true.

In 2009, Canadian researchers successfully converted human skin cells into stem cells. Although their technique did not yield a 100 percent success rate, it still represents an important step toward using stem cells for therapeutic treatment.

Resource Link

For further information, refer to the following website:

McIlroy, Anne. "Canadians Make Stem-Cell Breakthrough." *Globe and Mail*. 2 Mar. 2009. www.theglobeandmail.com/news/technology/science/article975588.ece (9 June 2011).

Cell-Replacement Therapy

Early thinking predicted that if stem cells could be isolated and cultured, they could be induced to become a particular type of tissue. The thinking was that if an adult needed healthy skin tissue or pancreatic tissue and if a stem cell from that person could be isolated and cultured, the cell mass could be reintroduced into the patient. These introduced cells would not be rejected by the patient's immune system since they would be "self" cells. This approach is referred to as cell-replacement therapy. In theory, this line of stem cell research seemed to hold great promise. In fact, in 1998, human embryonic stem cells were successfully isolated and cultured by James Thomson at the University of Wisconsin.

Sources of Stem Cells

Stem cells can be obtained from various sources that include the human embryo, the human fetus, the placenta, the umbilical cord, and the adult body. Embryonic cells tend to be relatively easy to grow in culture and have well-documented flexibility in terms of developing into various tissue types. Adult stem cells appear to have less ability to differentiate into all the body's cell types. They are also more difficult to obtain, since they are present in small quantities in the adult. They appear to decrease in number as the adult ages. Adult stem cell research holds great potential, however, because if adult stem cells could be induced to become particular cell types, transplanting them back into the adult would cause no immune rejection. Also, if more stem cells were required for that patient, they could be obtained when needed. Adult stem cells also appear to be less prone to promoting tumour growth.

Recent Work with Stem Cells

In 1994, patients with damaged corneas were successfully treated with corneal stem cells in Taiwan. In 1999, Canadian scientists working with researchers from Italy derived human blood cells from stem cells taken from nervous system cells. In 2002, California became the first state to legalize the cloning of embryos to produce stem cells for scientific and medical purposes. In 2004, research showed that diabetic mice could be cured with embryonic stem cells.

In April 2008, scientists in Toronto used human embryonic stem cells to grow human cardiac cells in a petri dish. The cell mass actually pulsated just as cardiac tissue would be expected to contract and relax rhythmically. The cardiac cells grown in culture had not been taken from a human donor. This research will be very important in drug research and may ultimately lead to the medical ability to repair damaged hearts using cultured cells.

In June 2008, two patients suffering from pulmonary hypertension were treated in a Montreal hospital with their own gene-modified stem cells. This therapy is the first in the world to use patient stem cells that have been genetically modified and reintroduced in the patient's body to treat pulmonary disease. A similar procedure cured laboratory rats of pulmonary hypertension.

Ethical Considerations

The use of stem cells to grow tissues for transplant is quite different from research that is aimed at creating a cloned human. In 2001, researchers in Massachusetts successfully cloned human embryos for the first time; however, those embryos died after only a few divisions.

Clearly, one line of controversy concerning the issue of cloning human embryos centres on the fact that many people consider human embryos to be living individuals; they consider the destruction of human embryos to be murder. Keep in mind that stem cells and embryos are not the same thing. Stem cells are diploid cells that can be isolated from an embryo or from a child or an adult. Embryos are the result of the fertilization of an egg cell by a sperm cell; embryos can be artificially implanted into the uterus of a woman. It is the scientific use of embryos by researchers who do not intend to let the embryo develop into a fetus that is controversial.

Xenotransplantation

Another area of research is *xenotransplantation*, the surgical transfer of cells, tissues, or organs from one organism into another organism belonging to another species. It is a term that often refers specifically to the transplantation of non-human cells, tissues, or organs into human recipients.

Xenotransplantation Research

In Scotland, for example, continuing research is aimed at genetically modifying pigs so that their organs could be transplanted into humans without being rejected. This option would alleviate the current shortage of human organs available for transplant and could potentially save many lives. Researchers in xenotransplantation predict that the transplant could be a complete substitute for human tissue in the future, or that it might provide a "bridge" between the diseased organ and a human organ when it becomes available.

It might seem to make more sense to use non-human primate donors instead of pigs for organ transplants, since humans are more closely related to monkeys and apes. However, since those primate species are genetically close to humans, the transfer of infectious agents would be even more likely. Pigs seem to be the most promising choice for donors because their organs are approximately the same size as human organs.

Cellular transplantation could be useful in treating people with diabetes, Alzheimer disease, and Parkinson disease. Tissue xenotransplantations could be used to provide skin grafts for burn victims, corneal transplants for the visually impaired, and bone grafts for accident victims. Whole organ xenotransplantation could involve hearts, lungs, livers, kidneys, or pancreases.

Another line of research studies the possibility of altering cells in cattle so that they would produce human antibodies that could be drawn out and used to treat humans for a variety of health problems, such as cancer and immune deficiencies.

Tissue Rejection

One stumbling block to xenotransplantation is that bacteria and viruses present in the tissue or organ transplanted from the donor animal could infect the human recipient. This type of infection is referred to as *xenosis* and would pose public health concerns if a non-human disease were to become a threat to humans. Rejection of tissue and organs from other species is also a substantial threat to the success of xenotransplantation; it is feared that the amount of immunosuppression required could leave the patient too susceptible to other diseases. Blood also tends to clot around xenotransplants, an obstacle that is being addressed by current research.

Other Areas of Research

A discussion of some other areas of research related to the application of gene technology follows.

Humulin

In 1982, synthetic human insulin, called Humulin, was approved by the United States Food and Drug Association. Humulin was licensed to and manufactured by the pharmaceutical company Eli Lilly and Company. Humulin is synthesized in a special non-disease-producing laboratory strain of bacteria that has been genetically modified to produce human insulin in a laboratory setting. This research development has been important to people with diabetes whose bodies are not capable of either making or using their own insulin.

New research aimed at turning one cell type into another without using cloning technology is continuing. For example, if the membrane of a defective cell could be made porous to proteins produced by healthy cells, the defective cell could acquire whatever structural or functional trait the protein conferred to it.

Methylation

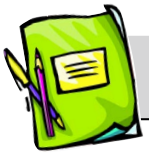
A fascinating area of genetics research is the use of plants in studying and treating human disease. It is known that some cancer cells "turn off" protector cells that normally attack tumours. As a result, those cancer cells can grow uncontrolled. The protector cells are "turned off" when the cancer cells attach methyl groups to their cell membranes. If we understood the mechanism behind this methylation, we would know better how to treat those types of cancer.

Steven Jacobsen, a plant biologist at the University of California, has discovered that some mustard plant cells can turn off particular genes by chemically attaching methyl groups to their surface. This allows the plant cell to regulate gene expression. DNA methylation is one way that genes can be controlled without changing the actual DNA sequence. Jacobsen is studying the mechanism of DNA methylation so that knowledge gained may be used in cancer research as well. More commonly used species such as mould, fruit flies, and mice do not possess the DNA methylation feature. It is particularly amazing that DNA methylation in a plant can be used to study DNA methylation in human cells as well.

The use of the mustard plant in further studies concerning human health has great potential. It has been found that at least 139 genes that cause human disease have counterparts in the mustard plant genome. Also, plant cells readily incorporate introduced DNA into their own DNA. Some of the controversy that surrounds the use of animals, especially mammals, in scientific research could be avoided if plants were used instead.

Genetic Screening

A final example of how genetic research can be applied involves genetic screening of human embryos. In June 2008, a woman in Great Britain conceived the first baby guaranteed to be free of the BRCA-1 gene for hereditary breast cancer. More than 50 percent of the individuals who carry that gene have been found to develop hereditary breast cancer. The gene is also linked to a higher than average incidence of ovarian cancer in women and of prostate cancer in men. The woman in Great Britain and her husband underwent pre-implantation genetic diagnosis (PGD) in which embryos resulting from in vitro fertilization (IVF) involving her eggs and his sperm were screened for the gene. Two healthy embryos were implanted and, in late June 2008, the woman was about 14 weeks pregnant. Two other healthy embryos were frozen for possible implantation in the future. This story provides one example of how genetic screening can be applied in the field of human health; future applications of this technology will have amazing effects on the lives of patients involved.



Learning Activity 2.5: Applications of Genetic Knowledge

This learning activity will give you an opportunity to review and reflect on what you have learned about the applications of genetic knowledge. Please record your responses in your notebook.

1. Define each of the following terms relating to gene technology:
   a) recombinant DNA
   b) transgenic organism
   c) cloning
   d) stem cell research
   e) OncoMouse
   f) xenotransplantation
   g) Humulin
2. As you review this lesson, find three issues relating to gene technology that are controversial. Explain why you believe each issue is controversial, and briefly explain how you feel about the issue and why you feel that way.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 2.5. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about several different applications of genetic knowledge. You have learned that these applications include some that involve biological resources and some that have an impact on human health and welfare. You have also seen that issues related to gene technologies are often surrounded by controversy. Certainly, scientific knowledge about gene technologies has preceded and outrun our ability to deal with the ethical decisions regarding their applications in society. That is, we know **how** to do some things that we don't yet know whether we **should** do. As a result, the applications of gene technologies become not only a scientific concern, but also a political, economic, and ethical concern.

Assignment 2.5: Applications of Genetic Knowledge (28 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 2.

For this assignment, you will examine reputable Internet sources to look for feature articles about the **application of gene technology in either biological resource management or human health and welfare**. Please find two articles on the specified topic. If you do not have access to the Internet, please find two articles on the topic from a print source (e.g., book, magazine, newspaper). **You will need to submit copies of the two articles with this assignment.**

For **each** of the two articles you selected, provide the following information (either typed or handwritten). **Attach your responses to each article.** *(28 marks total—14 marks for each article)*

Article 1

1. Provide source identification. Specify the author(s) of the article, the title of the article, the name of the publication or website, the website address (or the place of publication and the publisher), the date of publication, and the date you accessed the source. *(1 mark)*

2. Identify the name of the genetic technology tool(s) discussed in the article. *(1 mark)*

(continued)

Assignment 2.5: Applications of Genetic Knowledge (continued)

3. Summarize the content of the article, limited to three to five sentences. *(3 marks)*

4. Provide a statement summarizing any controversial issue related to the genetic technology tool(s) discussed in the article. The controversial issue may be either stated in the article or stated by you after reading the article. *(3 marks)*

5. Discuss the issue posed by the article. What do you think about it? Why? What viewpoints could other people have concerning it? *(3 marks)*

6. Address the implications of the gene technology discussed in the article. What implications of the gene technology are there in terms of societal, global, and personal concerns? *(3 marks)*

(continued)

Assignment 2.5: Applications of Genetic Knowledge (continued)

Article 2

1. Provide source identification. Specify the author(s) of the article, the title of the article, the name of the publication or website, the website address (or the place of publication and the publisher), the date of publication, and the date you accessed the source. *(1 mark)*

2. Identify the name of the genetic technology tool(s) discussed in the article. *(1 mark)*

3. Summarize the content of the article, limited to three to five sentences. *(3 marks)*

(continued)

Assignment 2.5: Applications of Genetic Knowledge (continued)

4. Provide a statement summarizing any controversial issue related to the genetic technology tool(s) discussed in the article. The controversial issue may be either stated in the article or stated by you after reading the article. *(3 marks)*

5. Discuss the issue posed by the article. What do you think about it? Why? What viewpoints could other people have concerning it? *(3 marks)*

6. Address the implications of the gene technology discussed in the article. What implications of the gene technology are there in terms of societal, global, and personal concerns? *(3 marks)*

Module 2 Summary

Congratulations! You have almost finished Module 2 of this course. The final lesson in Module 2 will help you to prepare for your midterm examination.

Submitting Your Assignments

It is now time for you to submit your assignments from Module 2 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 2 assignments and organize your material in the following order:

- ❑ Cover Sheet for Module 2 (found at the end of the course Introduction)
- ❑ Assignment 2.1: The Discovery of DNA
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- ❑ Assignment 2.4: Genetic Mutations
- ❑ Assignment 2.5: Applications of Genetic Knowledge

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

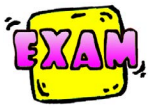
Notes

Lesson 6: Midterm Examination Review

Lesson Focus

This lesson does not address any specific learning outcomes.

Introduction



At the end of Module 2 of this course, you will write a midterm examination, which is based on Modules 1 and 2. When you have completed Module 5, you will write the final examination, which is based on Modules 3, 4, and 5. The midterm and final examinations are each worth 20 percent of the final course mark, for a total of 40 percent.

This lesson suggests some strategies you can use to study for the midterm examination. It also explains the examination format. You will learn what types of questions will appear on the midterm examination and what material will be assessed. Remember, your mark on the midterm examination determines 20 percent of your final course mark.

Requesting Your Examination

At the end of this lesson, you will write your midterm examination. If you have not yet made arrangements to write it, then do so now. The instructions are provided in the course Introduction.

Study Strategies

In preparing for the midterm examination, use the following study strategies:

- **Review all learning activities and assignments:** Revisit the work you completed in Modules 1 and 2. You could answer the questions in those exercises again, and then compare your answers with your original responses and with the Learning Activity Answer Key provided at the end of each module and with your tutor/marker's assessment of your completed assignments.

- **Review vocabulary:** A review of vocabulary terms is also an effective way to review concepts. You could practise defining terms from Modules 1 and 2, perhaps by using index cards (using one side for a term and the other side for its definition). Keep in mind that one section of the examination asks you to connect pairs of terms by explaining how they are related, so try to connect vocabulary terms to one another as you study their definitions.
- **Review the names and contributions of scientists:** The work of many scientists was presented and discussed in Modules 1 and 2. As you prepare for the examination, you could list the names of those scientists and then review the work that each person did. In doing so, you will study how the work of various scientists is related and has continued to add to current understanding of the biological world.
- **Review major concepts:** The sample questions that follow will give you some idea of the major concepts that may be addressed in the long-answer section of the examination. As you study, you could outline an answer that explains each major concept. You will already have studied many of these concepts when you reviewed the learning activities and assignments from Modules 1 and 2 and when you studied the vocabulary from those two modules.

Examination Format

The midterm examination consists of the following five types of questions, the values of which combine to a total of 100 marks.

True or False ***(25 marks)***

In this section of the examination, you will decide whether each of the 25 statements is true or false, and you will indicate your choice by printing either T or F in the space provided for each statement.

Multiple Choice ***(15 marks)***

In this section, you will choose the single best answer to each of the questions given.

Matching ***(15 marks)***

In this section, you will match a list of 15 terms with their corresponding definitions. Each definition will be used only once.

Definitions and Connections ***(15 marks)***

In this section, you will choose five pairs of terms (out of seven pairs given). For each pair, you will define each term and then explain how the two terms are related.

Long Answer ***(30 marks)***

In this section, you will choose six long-answer questions (of the eight questions given). You will be asked to answer each selected question clearly and thoroughly in the space provided.

Sample Questions

Some sample examination questions are presented below. *Answers to the questions are provided in italic.*

True or False

1. A woman who is homozygous recessive for a recessive sex-linked trait is a carrier for that trait.

   False – Homozygous individuals are not carriers. Carriers are always heterozygous.

2. DNA and RNA are nucleic acid molecules that are composed of building blocks called nucleotides.

   True

3. A zygote is produced by the fusion of two haploid gametes.

   True

4. An example of a sex-linked recessive disease is hemophilia.

   True

5. The scientist who discovered the double helix structure of DNA was Gregor Mendel.

   False – Gregor Mendel lived long before the molecular structure of DNA was discovered and explained.

Multiple Choice

1. Meiosis is a process that produces
   a) diploid gametes from diploid parent cells
   b) haploid gametes from haploid parent cells
   c) diploid gametes from haploid parent cells
   d) haploid gametes from diploid parent cells

2. Germ-line mutations occur in
   a) skin cells
   b) reproductive cells
   c) muscle cells
   d) nerve cells

3. Gregor Mendel's *factors* are now called
   a) pedigrees
   b) mutations
   c) genes
   d) zygotes

4. Flexible cells that can give rise to many specialized types of cells are called
   a) gametes
   b) stem cells
   c) mutant cells
   d) zygotes

5. Transplanting cells from one organism into another organism that belongs to another species is called
   a) cloning
   b) stem cell research
   c) genetic mutation
   d) xenotransplantation

Matching

E	1. replication	A. A genetic cross that involves two traits.
A	2. dihybrid	B. An error during meiosis that can result in either monosomies or trisomies in the offspring.
D	3. ultrasound	C. Viruses that attack bacteria.
B	4. nondisjunction	D. A genetic screening technique using sound waves.
C	5. phages	E. The process in which DNA copies itself in the nucleus of the cell.

Definitions and Connections

1. *DNA* and *RNA*
   - *DNA is deoxyribonucleic acid; it is the molecule that makes up genetic material in living cells. It is in the shape of a double helix and is in the cell's nucleus.*
   - *RNA is ribonucleic acid; it is a single-stranded molecule that carries the genetic material from the cell's nucleus into the cytoplasm where ribosomes are located for protein production.*
   - *Both molecules are nucleic acids and both are important in heredity. They carry information about which proteins a certain cell should make, thereby determining the characteristics of that cell.*
2. *replication* and *transcription*
   - *Replication occurs when a DNA molecule is copied in the nucleus of a cell. Replication must occur in order for a cell to reproduce so that the diploid chromosome number is maintained.*
   - *Transcription occurs when DNA is used as a template for producing single-stranded RNA molecules. RNA travels out of the cell nucleus and attaches to a ribosome where proteins are produced.*
   - *These two processes are important in that they both involve the molecules of heredity in the cell – DNA and RNA.*

Long Answer

A list of topics that could be addressed in long-answer questions on the midterm examination is given below. After you have reviewed your knowledge about each topic, you could refer to the course material to check for accuracy and completeness.

1. The structure of the DNA molecule
2. Differences and similarities that exist between DNA molecules and RNA molecules
3. The stages of meiosis and how they differ from the stages of mitosis
4. The important contributions of scientists such as Owald Avery, Alfred Hershey and Martha Chase, James Watson and Francis Crick, and Friedrich Miescher
5. Various types of mutations, such as small-scale and large-scale mutations, and the effects they have on living cells
6. Various issues related to genetic research, such as cloning, xenotransplantation, the use of GMOs, stem cell research, and genetic screening
7. Using a Punnett square to predict the genotypes and phenotypes of the offspring produced in a particular genetic cross
8. Interpreting pedigrees and predicting the genotypes of particular individuals
9. Gregor Mendel's laws of inheritance
10. Given a short DNA strand, identifying the mRNA transcribed from it and the peptide chain built using its base sequence

Summary

Good luck as you prepare for the midterm examination. If you have completed all the learning activities and assignments from Modules 1 and 2, and have used the suggested strategies in studying for the examination, you have prepared yourself well. The examination will provide an opportunity for you to show what you know.

Module 2 Summary

Congratulations! You have almost finished Module 2 of this course. The final lesson in Module 2 will help you to prepare for your midterm examination.

Submitting Your Assignments

It is now time for you to submit your assignments from Module 2 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 2 assignments and organize your material in the following order:

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- ❑ Assignment 2.4: Genetic Mutations
- ❑ Assignment 2.5: Applications of Genetic Knowledge

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

Notes

Grade 12 Biology (40S)

Module 2
Mechanisms of Inheritance

Learning Activity Answer Key

Module 2:
Mechanisms of Inheritance

Learning Activity 2.1: A Timeline of the Discovery of DNA

For this learning activity, you considered how our understanding of the mechanics of inheritance has changed over the last 150 years.

1. Construct a timeline that chronologically outlines major scientific discoveries that have led to our current understanding of DNA, and name the scientists who made the discoveries. Begin with Gregor Mendel and continue up to the present.

   You can use a horizontal or a vertical timeline to organize the events named in this lesson. The events should be recorded roughly in this order of occurrence:

   - 1865: Mendel—identified inheritance patterns in pea plants
   - 1871: Miescher—isolated nuclein
   - 1900: Correns—clarified Mendel's conclusions

     de Vries and von Tschermak-Seysenegg—provided experimental support for Mendel's conclusions
   - 1915: Morgan—suggested a chromosomal theory of inheritance

     Muller—showed that X-rays could cause gene mutations
   - 1929: McClintock—showed mutations of corn chromosomes
   - 1940: Beadle and Tatum—proposed the "one gene–one enzyme" hypothesis
   - 1944: Avery—discovered transformation of bacteria caused by DNA
   - 1951: Franklin—produced X-ray crystallography pictures of DNA
   - 1952: Hershey and Chase—showed the importance of viral DNA in viral reproduction
   - 1953: Kornberg—isolated enzyme involved in DNA replication
   - 1954: Jacob and Monod—worked on the *lac operon* model of gene action
   - 1956: Brenner—researched codons and the amino acids they code for
   - 1957: Zamecnik and Hoagland—determined the identity of tRNA and studied protein synthesis

     Meselson and Stahl—clarified DNA replication
   - 1958: Sanger—identified the protein sequence

- 1961: Nirenberg—worked out the entire genetic code (codons and amino acids)
- 1962: Watson and Crick—proposed the chemical structure of the double helix
- 1964: Benzer—connected a certain gene to a certain trait
- 1972: Cohen and Boyer—developed ideas about recombinant DNA technology
- 1975: Roberts—identified enzymes that could cut DNA; promoted computer use in molecular biology
- 1980: Capecchi—studied how genes could be mutated intentionally
- 1989: Fodor—invented the first GeneChip

  Collins—found the gene for cystic fibrosis

  Sulston—showed how gene control of cell differentiation and specialization occurs in the nematode worm
- 1990: King—identified the first breast cancer gene
- 2000: Venter—used sequencing computers to finish assembling the entire human genome
- 2003: Human Genome Project—project completed; about 1400 disease genes identified in humans

Learning Activity 2.2: The Structure of DNA

This learning activity gave you an opportunity to review what you had learned about the structure of DNA.

1. Suppose that the sequence of bases on one side of a DNA molecule is adenine, cytosine, thymine, guanine. What is the sequence of bases on the other side of each "rung" that matches it?

   Thymine – guanine – adenine – cytosine

2. What chemicals are found in a nucleotide?

   The three chemicals found in a nucleotide are: a five-carbon sugar, a phosphate group, and a nitrogen-containing organic base.

3. Who were the co-discoverers of the double-helix model of DNA?

   Francis Crick and James Watson

Learning Activity 2.3: Replication, Transcription, and Translation

This learning activity gave you an opportunity to review what you had learned about replication, transcription, and translation.

1. Compare the three processes—replication, transcription, and translation—in terms of
   a) the location where the process occurs in the cell
   b) the end product of the process in the cell

	Location	**End Product**
Replication	nucleus	exact copy of the DNA double helix
Transcription	nucleus	mRNA strand
Translation	cytoplasm (on ribosome)	protein

2. Compare the three molecules—DNA, mRNA, and tRNA—in terms of
   a) their location in the cell
   b) organic bases present
   c) their overall structure
   d) the sugar molecule present in each nucleotide
   e) their function in the cell with respect to protein synthesis

	DNA	**mRNA**	**tRNA**
Location	nucleus	nucleus, then cytoplasm	cytoplasm
Bases	A, T, G, and C	A, U, G, and C	A, U, G, and C
Structure	double-stranded helix	single-stranded	three nucleotides on one end; amino acid on the other end
Sugar	deoxyribose	ribose	ribose
Function	genetic code of the cell	carries code from nucleus into cytoplasm	translation—brings correct amino acid into position

3. Explain, as clearly as you can, how genotype determines phenotype.

   The genes present in a cell determine which proteins the cell will make. Proteins are the structural and functional molecules that determine phenotype—how a cell looks and acts.

Learning Activity 2.4: Genetic Mutations

This learning activity gave you an opportunity to review what you had learned about genetic mutations.

1. The DNA sequence of a gene can be compared to a sentence made up entirely of three-letter words and without spaces. An example follows:

   thesunwashotbuttheoldmandidnotgethishat

   This sentence, considered as triplets of letters, reads as follows:

   the sun was hot but the old man did not get his hat

   a) Mimic an **insertion mutation** by inserting a random letter into the sentence. How does this insertion affect the sentence?

      Many possible insertions can be made. An example follows:

      the sun was hoi tbu tth eol dma ndi dno tge thi sha t

      The sentence has lost its meaning.

   b) Mimic a **deletion mutation** by deleting a random letter from the sentence. How does this affect the sentence?

      Many possible deletions can be made. An example follows:

      the sun was hob utt heo ldm and idn otg eth ish at

      The sentence has lost its meaning.

   c) Mimic a **point mutation** by substituting a random letter into the sentence. How does this affect the sentence?

      Many possible substitutions can be made. An example follows:

      the sun was hot zut the old man did not get his hat

      The meaning here is altered but not as dramatically. Remember that an altered triplet means an altered amino acid in most cases.

   d) Mimic an **inversion mutation** by reversing a word in the sentence. How does this affect the sentence?

      Many possible deletions can be made. An example follows:

      the sun was hot but the dlo man did not get his hat

      Again, the meaning is altered but not as dramatically. Remember that an altered triplet means an altered amino acid in most cases.

2. Explain the following statement: "Genetic mutations are the raw material that natural selection acts upon."

   Genetic mutations are changes in the genetic information possessed by the cell. Often, genetic mutations cause changes in phenotype. These phenotypic changes may make the organism possessing them better adapted to its environment. In this case, the organism will have an adaptive advantage and a reproductive advantage. As a result, the mutated genes will become more common in the population over time. Natural selection is the mechanism of evolution; a reproductive advantage that results from mutation leads to genetic change over time. Remember that the environment of the organism defines which traits will give reproductive advantages to the organisms possessing them.

Learning Activity 2.5: Applications of Genetic Knowledge

This learning activity gave you an opportunity to review and reflect on what you had learned about the applications of genetic knowledge.

1. Define each of the following terms relating to gene technology:

   a) recombinant DNA

   A very broad term often used to name the process of combining DNA material from various sources. It is one type of genetic engineering technology.

   b) transgenic organism

   An organism that possesses DNA belonging to another species. Transgenic organisms do not normally exist in nature; they are the result of human manipulation.

   c) cloning

   The use of either an embryonic cell or a somatic cell to create a new organism with the original cell's DNA. Scientists have far more knowledge about cloning non-human species than about cloning humans.

   d) stem cell research

   Research involving stem cells, which are able to divide repeatedly while still retaining the ability to differentiate into a variety of cell types.

   e) OncoMouse

   A transgenic mouse, patented in 1988, that was very susceptible to cancer and useful in cancer research. In 1989, the DuPont company took over its use in genetic research.

   f) xenotransplantation

   The transplantation of a cell, tissue, or organ from an individual of one species into an individual belonging to another species. Most often, the donor species is non-human and the recipient is human.

   g) Humulin

   Synthetic human insulin produced by a strain of bacteria that has been genetically modified.

2. As you review this lesson, find three issues relating to gene technology that are controversial. Explain why you believe each issue is controversial, and briefly explain how you feel about the issue and why you feel that way.

   The answers that you could give to this question are varied and depend on your personal beliefs and your life experience. Examples of controversial issues related to genetic research are

   - the use of human embryos for stem cell research
   - the use of non-human animals in medical research
   - GMOs
   - xenotransplantation that would involve the death of the donor organism

Biology Videos

Module 2

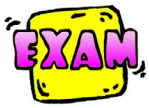
1. Video - The Discovery of the Structure of DNA
2. Video - DNA Structure and Replication: Crash Course Biology #10
3. Video - DNA replication and RNA transcription and translation | Khan Academy
4. Video - DNA Replication: The Cell's Extreme Team Sport
5. Video - DNA Mutation 3D Animation
6. Video - An introduction to genetic mutations | Biomolecules | MCAT | Khan Academy
7. Video - Genetic Engineering in Agriculture: The Future of Food
8. Video - Biotechnology: Genetic Modification, Cloning, Stem Cells, and Beyond
9. Video - Designer Babies: The Science and Ethics of Genetic Engineering
10. Video - The Ethics of Human Gene Editing: Unnatural Selection

Lesson 6: Midterm Examination Review

Lesson Focus

This lesson does not address any specific learning outcomes.

Introduction



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Requesting Your Examination

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Study Strategies

In preparing for the midterm examination, use the following study strategies:

- **Review all learning activities and assignments:** Revisit the work you completed in Modules 1 and 2. You could answer the questions in those exercises again, and then compare your answers with your original responses and with the Learning Activity Answer Key provided at the end of each module and with your tutor/marker's assessment of your completed assignments.

- **Review vocabulary:** A review of vocabulary terms is also an effective way to review concepts. You could practise defining terms from Modules 1 and 2, perhaps by using index cards (using one side for a term and the other side for its definition). Keep in mind that one section of the examination asks you to connect pairs of terms by explaining how they are related, so try to connect vocabulary terms to one another as you study their definitions.
- **Review the names and contributions of scientists:** The work of many scientists was presented and discussed in Modules 1 and 2. As you prepare for the examination, you could list the names of those scientists and then review the work that each person did. In doing so, you will study how the work of various scientists is related and has continued to add to current understanding of the biological world.
- **Review major concepts:** The sample questions that follow will give you some idea of the major concepts that may be addressed in the long-answer section of the examination. As you study, you could outline an answer that explains each major concept. You will already have studied many of these concepts when you reviewed the learning activities and assignments from Modules 1 and 2 and when you studied the vocabulary from those two modules.

Examination Format

The midterm examination consists of the following five types of questions, the values of which combine to a total of 100 marks.

True or False ***(25 marks)***

In this section of the examination, you will decide whether each of the 25 statements is true or false, and you will indicate your choice by printing either T or F in the space provided for each statement.

Multiple Choice ***(15 marks)***

In this section, you will choose the single best answer to each of the questions given.

Matching ***(15 marks)***

In this section, you will match a list of 15 terms with their corresponding definitions. Each definition will be used only once.

Definitions and Connections ***(15 marks)***

In this section, you will choose five pairs of terms (out of seven pairs given). For each pair, you will define each term and then explain how the two terms are related.

Long Answer ***(30 marks)***

In this section, you will choose six long-answer questions (of the eight questions given). You will be asked to answer each selected question clearly and thoroughly in the space provided.

Sample Questions

Some sample examination questions are presented below. *Answers to the questions are provided in italic.*

True or False

1. A woman who is homozygous recessive for a recessive sex-linked trait is a carrier for that trait.

   False – Homozygous individuals are not carriers. Carriers are always heterozygous.

2. DNA and RNA are nucleic acid molecules that are composed of building blocks called nucleotides.

   True

3. A zygote is produced by the fusion of two haploid gametes.

   True

4. An example of a sex-linked recessive disease is hemophilia.

   True

5. The scientist who discovered the double helix structure of DNA was Gregor Mendel.

   False – Gregor Mendel lived long before the molecular structure of DNA was discovered and explained.

Multiple Choice

1. Meiosis is a process that produces
   a) diploid gametes from diploid parent cells
   b) haploid gametes from haploid parent cells
   c) diploid gametes from haploid parent cells
   d) haploid gametes from diploid parent cells

2. Germ-line mutations occur in
   a) skin cells
   b) reproductive cells
   c) muscle cells
   d) nerve cells

3. Gregor Mendel's *factors* are now called
   a) pedigrees
   b) mutations
   c) genes
   d) zygotes

4. Flexible cells that can give rise to many specialized types of cells are called
   a) gametes
   b) stem cells
   c) mutant cells
   d) zygotes

5. Transplanting cells from one organism into another organism that belongs to another species is called
   a) cloning
   b) stem cell research
   c) genetic mutation
   d) xenotransplantation

Matching

E	1. replication	A. A genetic cross that involves two traits.
A	2. dihybrid	B. An error during meiosis that can result in either monosomies or trisomies in the offspring.
D	3. ultrasound	C. Viruses that attack bacteria.
B	4. nondisjunction	D. A genetic screening technique using sound waves.
C	5. phages	E. The process in which DNA copies itself in the nucleus of the cell.

Definitions and Connections

1. *DNA* and *RNA*
   - *DNA is deoxyribonucleic acid; it is the molecule that makes up genetic material in living cells. It is in the shape of a double helix and is in the cell's nucleus.*
   - *RNA is ribonucleic acid; it is a single-stranded molecule that carries the genetic material from the cell's nucleus into the cytoplasm where ribosomes are located for protein production.*
   - *Both molecules are nucleic acids and both are important in heredity. They carry information about which proteins a certain cell should make, thereby determining the characteristics of that cell.*
2. *replication* and *transcription*
   - *Replication occurs when a DNA molecule is copied in the nucleus of a cell. Replication must occur in order for a cell to reproduce so that the diploid chromosome number is maintained.*
   - *Transcription occurs when DNA is used as a template for producing single-stranded RNA molecules. RNA travels out of the cell nucleus and attaches to a ribosome where proteins are produced.*
   - *These two processes are important in that they both involve the molecules of heredity in the cell – DNA and RNA.*

Long Answer

A list of topics that could be addressed in long-answer questions on the midterm examination is given below. After you have reviewed your knowledge about each topic, you could refer to the course material to check for accuracy and completeness.

1. The structure of the DNA molecule
2. Differences and similarities that exist between DNA molecules and RNA molecules
3. The stages of meiosis and how they differ from the stages of mitosis
4. The important contributions of scientists such as Owald Avery, Alfred Hershey and Martha Chase, James Watson and Francis Crick, and Friedrich Miescher
5. Various types of mutations, such as small-scale and large-scale mutations, and the effects they have on living cells
6. Various issues related to genetic research, such as cloning, xenotransplantation, the use of GMOs, stem cell research, and genetic screening
7. Using a Punnett square to predict the genotypes and phenotypes of the offspring produced in a particular genetic cross
8. Interpreting pedigrees and predicting the genotypes of particular individuals
9. Gregor Mendel's laws of inheritance
10. Given a short DNA strand, identifying the mRNA transcribed from it and the peptide chain built using its base sequence

Summary

Good luck as you prepare for the midterm examination. If you have completed all the learning activities and assignments from Modules 1 and 2, and have used the suggested strategies in studying for the examination, you have prepared yourself well. The examination will provide an opportunity for you to show what you know.

GRADE 12 BIOLOGY (40S)

Module 3
Evolutionary Theory and Biodiversity

Module 3:
Evolutionary Theory and Biodiversity

Introduction

About 1000 kilometres west of Ecuador, South America, a group of volcanic islands, called the Galapagos Islands, forms an archipelago that lies on the equator. This archipelago is made up of 16 main islands, six smaller islands, and 10 islets. These tropical islands display an amazing amount of biological diversity. At one time, the Galapagos Islands were called the Enchanted Islands, both because of their beauty and because of the strong currents surrounding them that made navigation difficult.

This chain of islands is famous for a number of reasons, including the remarkably high number of species found only on the Galapagos. Particularly amazing is the bird life found on these tiny islands separated by about 1000 kilometres from the mainland. Only two types of land birds are found on the Galapagos: finches and mockingbirds. In all, about 13 species of finches and four species of mockingbirds are found on the islands, none of which is found anywhere else in the world—including Ecuador itself.

The finch species found on the Galapagos have an amazing pattern of adaptation. Each of the endemic species of finches has distinct physical features that allow the finches to eat a very specific type of food. Their beaks have distinct and specialized shapes that can be linked to their food choices. One finch, the sharp-beaked ground finch, sucks blood from its source of food. Another, the woodpecker finch, uses twigs to pull insects out of tree trunks and branches. Some of the finch species eat seeds, while others eat insects.

Many questions arise from this information. Why are no mainland bird species, other than those able to fly long distances, found on the islands? Why are the bird species that are endemic to the islands not found on the mainland? Why are so many kinds of finches found on the Galapagos? Since the islands are volcanic, they have never been joined to the mainland, so how did the finches get there in the first place?

These questions, among many others, fascinated a young explorer named Charles Darwin in the mid-1800s. You will learn about his famous voyage to the Galapagos Islands and about some of his conclusions regarding the biological diversity he found on the islands. Darwin not only established the foundation for recognizing evolution as a reality in the biological world, but he also explained a mechanism for how evolution could proceed: natural selection.

Module 3 Assignments

When you have completed the assignments for Module 3, submit your completed assignments to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 3.1	Science and Evolution
2	Assignment 3.2	Theories of Evolutionary Change
3	Assignment 3.3	Adaptation
4	Assignment 3.4	Population Genetics
5	Assignment 3.5	Evolution and Speciation

Lesson 1: Science and Evolution

Lesson Focus

In this lesson, you will

- ❑ define the term *evolution*, explaining how evolution has led to biodiversity by altering populations and individuals
  Include: gene pool and genome

Introduction

In the first two modules of this course, you learned about the fascinating study of genetics and inheritance. You learned that the traits an organism possesses are controlled by the particular genes inherited by that organism. You studied the details of the genotype–phenotype connection as you learned about the process of protein synthesis.

In this lesson, you will learn about the nature of scientific inquiry and the process of evolution. Your current understanding of genetics and heredity will be a firm foundation as you begin this module. In this lesson especially, try to compare what you learn about *science* and *evolution* to your prior understanding of these terms. Both words are used commonly in everyday life in ways that may not be pertinent to the content of this course. In other words, try to keep your mind open to the meanings of science and evolution as they are presented in this lesson.

What Is Science?

How do you define *science*? Is your definition based on examples of sciences, such as biology, with which you are familiar? What images come to your mind when you think of science? Who studies science? How do scientists conduct their work? What is the end product of their work? Does scientific study have any limitations? How does your understanding of science affect your understanding of evolution? These are some of the questions you will consider in this lesson.

Science: A Definition

If you consult a dictionary, you will find a definition of *science* that may be too broad for the purposes in this course. For example, astrology is sometimes referred to as a science even though it does not fit the definition of science that you will learn about in this lesson.

Naturally curious, we humans have developed science as a tool to help us answer questions about how things work and to help us understand the world. Knowledge gained through scientific inquiry is sometimes applied to improve the quality of human life. Therefore, there is a distinction between *basic science*, through which we seek knowledge, and *applied science*, through which we use knowledge for various purposes.

The Scientific Method

Scientists use a specific approach known as the *scientific method*. Humans did not discover the scientific method; they invented it. The scientific method is characterized by a number of important characteristics, such as those discussed below.

Steps in the Scientific Method

In previous science courses, you have probably learned the six essential steps in the scientific method:

1. **Ask a question** about the topic you will be investigating.
2. Do adequate **background research** regarding the question. What humans already know about the topic of inquiry must be thoroughly understood before further work can be done.
3. Make a **hypothesis** about the answer to the question. A hypothesis is a tentative answer to the question and is based on the background research that was already done.
4. Design an **experiment** that sheds light on the question being asked. A good scientific experiment must be controlled in terms of the variables that it involves.
5. Conduct the experiment and make objective **observations** about its results.
6. Draw **conclusions** that are based on the experimental results gathered during the experiment. These conclusions should refer back to the initial question that was asked and to the hypothesis that was made before the experimental design was completed. These conclusions should be very specific. At times, they may indicate areas for further study. For example, if the hypothesis is not supported by the experimental evidence, a new hypothesis may be made and a new experiment may be designed and conducted.

Consistency of Results

Scientists look for experimental results and observations that are consistent with one another and that show some kind of identifiable pattern. Experimental observations are factual. When a number of experimental observations are found to be consistent with each other, they may support a conclusion that is then referred to as a *theory*. Scientific theories may range from being very weak, with very little evidence for their validity, to very strong, with a great deal of experimental evidence for their validity. Theories in science are never proven. Facts, on the other hand, are true and do not need to be proven.

The Limitations of Science

Because science depends on human senses (taste, touch, sight, smell, and hearing) to make observations about the world, science can address only those questions that are related to observable phenomena. Questions dealing with other phenomena may be good questions, but they cannot be addressed by science. Other human pursuits such as art, philosophy, or religion may be able to address questions that lie outside the realm of scientific inquiry. Science is limited in its scope.

Tentative Explanations

Humans naturally have questions about many things in this world and beyond. Not all those questions can be addressed by science. However, when a substantial amount of experimental evidence supports an answer to a question that can be dealt with by scientific inquiry, then that answer may become a theory. As more and more evidence supports the answer, it becomes a stronger theory. A theory can be used to make predictions about how things work and can be studied through further experimentation and observation. As a result, theories in science are tentative in nature because they are subject to change if new evidence arises. Keep in mind that facts are not tentative.

Science and Evolution

It is important, in this lesson, to clarify what science means before addressing the subject of evolution. Whatever your prior knowledge is about evolution, keep in mind that this course addresses the subject from a *scientific* perspective. Conclusions about evolution are based on experimental results and observations. There are questions related to evolution that cannot be addressed by scientific inquiry; questions such as these may be very good questions nonetheless. Remember that *science is limited in its scope*.

What Is Evolution?

Knowing what evolution means helps us to understand it as a process in the natural world. Like the word *science*, the word *evolution* is used in everyday life in ways that are not important in this course.

Evolution: A Definition

In this course, *evolution* is defined as **the change that occurs in living things over time**. There is a vast amount of factual evidence that evolution occurs; however, ideas about *how* it occurs are continually changing as new information is gathered. Evolution is a fact because we can see it occurring. On the other hand, our ideas about the *mechanisms* of *how* evolution occurs are theoretical.

At this point, you may question the statement that "evolution is a fact." Remember that evolution is the change that occurs in living things over time. It is very important to emphasize that this change occurs in *populations* of organisms, not in *individual* organisms themselves. You will now look at some of the forms of evidence that support the statement that "the occurrence of evolution is a fact."

The Fossil Record

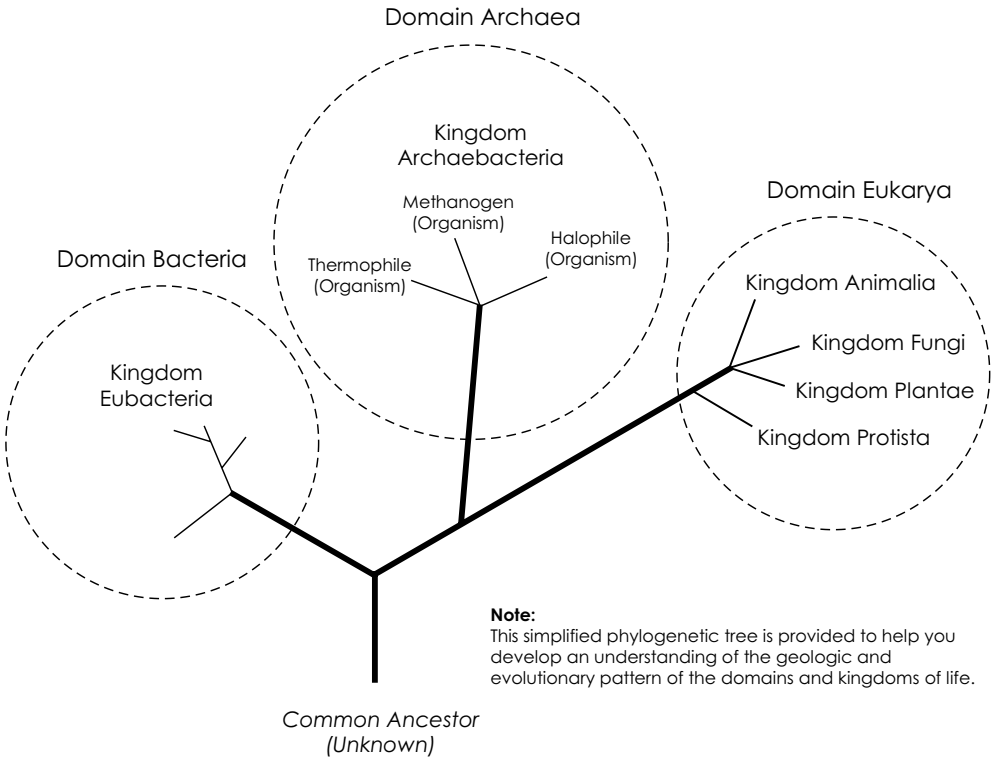
Paleontology is the study of fossils. *Fossils* are the physical remains of organisms from the past. We have the technology to date fossils. For example, the layer of rock in which fossils are found can be dated based on its thickness and its location. It is also possible to determine the age of rocks and the fossils in them using *radioactive dating* techniques. Radioactive elements decay over time at predictable rates; therefore, comparing the measured amount of a radioactive element in a specimen to the amount of its product after decay can provide a fairly accurate idea of how old the specimen is. Scientists from all over the world contribute their findings to a worldwide inventory of life forms from the past. As this inventory grows, we gain more and more information about the change that organisms have experienced over time. When we can date rock, we can date the fossils found in it.

Many fossils are formed from organisms that have long since become extinct. Other fossils represent organisms that have undergone very little change over long periods of time. Keep in mind that a complete fossil record of all species since life began on Earth will never be found. There are definite gaps in the fossil record; however, as each new fossil is unearthed and studied, the size of those gaps in paleontological knowledge is reduced.

Not all organisms that die are fossilized. Sometimes, their bodies are consumed or decomposed after death. Body parts such as bones and teeth are most easily fossilized because they are hard and most resistant to the agents of weathering. At times, entire organisms are found intact, locked in ice for thousands of years. Some insects have even been preserved in amber, a hardened gummy substance produced by trees.

It is currently believed that the Earth was formed about 4.5 billion years ago and that the first life forms appeared on it about 3.5 billion years ago. The average human life span is so short compared to these periods of time that it is very difficult to understand geologic time. When we summarize all the information we have about fossils, their ages and locations, and the physical similarities and differences between them, we begin to see a series of patterns. These patterns of relationships can be summarized in diagrams designed to illustrate change over time. Consider, for example, the phylogenetic tree of life shown in Figure 3.1.

Figure 3.1 **Phylogenetic Tree of Life**



Phylogenetic trees, such as the one above, can be drawn for all forms of life on Earth or for a specific group of living things. They show the geologic time scale over which the life forms have lived on Earth. The oldest life forms are represented by the trunk of the tree, and the more recent life forms are represented by its branches. Note that these trees of life are based on various forms of evidence, one of which is the fossil record.

Biochemical Analysis

When comparing the DNA from various organisms, scientists find that the more closely related organisms are, the more DNA segments they have in common. Similarities of various other chemicals, especially proteins, are also indicative of evolutionary relationships. A useful example to illustrate this concept is the relationship between humans and some of the apes. When human DNA is compared to chimpanzee DNA, about 1.2 percent of the sequences differ. Human DNA compared to gorilla DNA shows about 1.6 percent difference, and human DNA compared to the DNA of baboons shows about 6.6 percent difference. If human DNA were compared to the DNA from an organism that is not a primate, the difference would be much greater. Greater still would be the difference between human DNA and the DNA of an organism that is not a mammal.

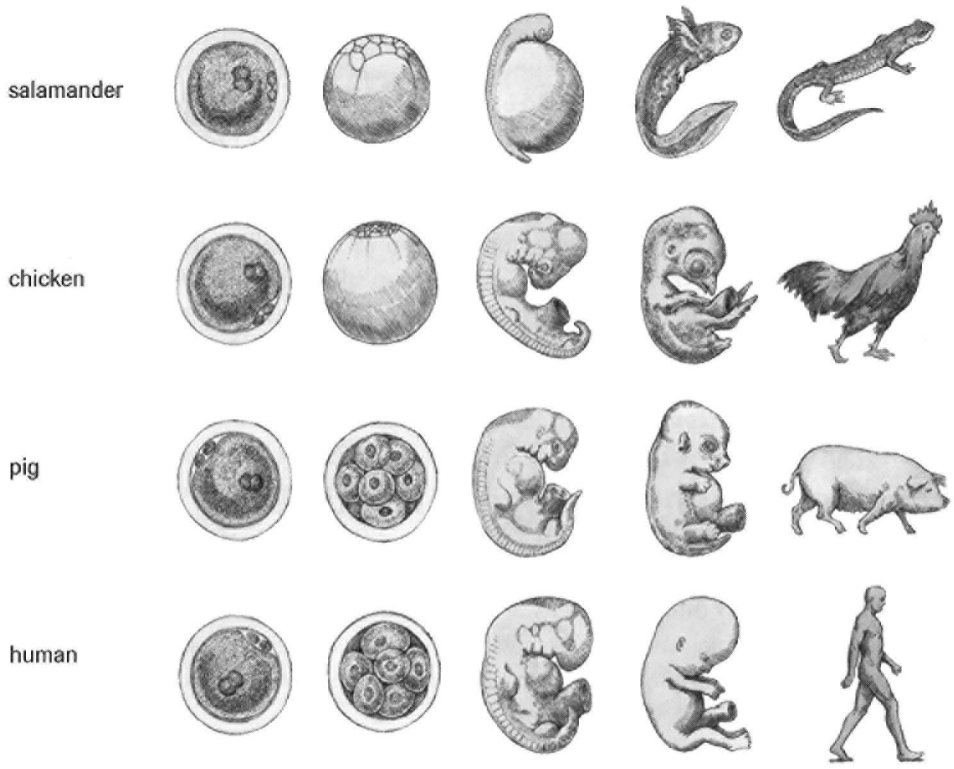
The fact that all living organisms possess a number of fundamental molecules indicates that they share a common ancestor. All life forms on Earth possess nucleic acids (such as DNA and RNA), adenosine triphosphate (ATP—the "energy currency" used by living cells), and some combination of the basic 20 amino acids that make up proteins. All life forms on Earth are built of organic molecules that are based on carbon chains, rings, or sheets. The composition of one particular protein, cytochrome (C), is a strong indicator of evolutionary relationship.

Embryology

Embryology is the study of the early stages of development of an organism. Recall that not all organisms are "born"; for example, some are hatched, while others are formed by asexual reproduction. A comparison of the early development of various multicellular organisms shows that the more closely related two organisms are, the more similar their patterns of development are.

For example, very early in development, the embryos of lizards, birds, and mammals are similar in structure. This indicates that these animals share a common ancestor. It does not indicate that mammals evolved from lizards or birds; instead, it indicates that mammals, lizards, and birds share a common ancestor. Consider the diagram in Figure 3.2, which shows three stages of embryological development in four different species.

Figure 3.2 **Stages of Embryological Development**



Source: Di Giuseppe, Maurice, et al. *Nelson Biology 12.* Toronto, ON: Nelson, a division of Thomson Canada Limited, 2003. 524.

Comparative Anatomy

A study of the anatomy of various organisms shows that closely related organisms possess anatomical structures in common. When different organisms share anatomical structures, those structures have the same evolutionary origins. This is true despite the fact that different organisms may use those structures in different ways. For example, the flipper of a whale, the wing of a bat, the leg of a horse, and the arm of a human all share the same basic anatomical structure. These four structures are, however, used in very different ways: whales use their flippers to swim, whereas humans use their arms to climb, type, and so on. Similar structures that serve different functions are called *homologous structures*.

In other cases, a comparison of two organisms on the basis of structure and function shows that the same function can be performed by structures that are not very similar. For example, the flipper of a whale and the fin of a fish serve similar functions but are very different anatomically. These structures are called *analogous structures*. These structures do not indicate close evolutionary relationships.

A look at vestigial structures provides a clue to understanding evolutionary relationships. A *vestigial structure* is an organ or body part that serves no apparent function for the organism possessing it. Vestigial structures are usually more underdeveloped in the organism than are the similar structures in the ancestral organism. It is thought that the structure served an adaptive purpose in the ancestor that is no longer needed in the descendant. For example, the ostrich possesses wings but does not fly; the presence of wings indicates that ostriches are related to other birds, most of which do use their wings to fly.

Biogeography

Biogeography is the study of how organisms on Earth are distributed geographically. By studying that distribution, we discover patterns that are useful in understanding how organisms have changed over time.

For example, geological studies indicate that the continents and islands as they exist on Earth today were not located in the same places in the past. This idea of *continental drift* suggests that the land masses on Earth have moved because of plate tectonics and, indeed, continue to move today. When we combine current knowledge about plate movements and evolutionary relationships, we see remarkable and important patterns. For example, fossil evidence suggests that camels originated in North America. Obviously, no camels have existed in the recent past in North America. Based on fossil evidence, it is believed that these ancient camel ancestors travelled in two directions, into South America and into Asia, crossing the Bering Strait land bridge when it existed. In South America, these animals evolved into present-day llamas. In Asia and later in Africa, they evolved into the various camel species existing today.

A comparison of the anatomy and biochemistry of camels and llamas reveals great similarities. Over thousands of years, a common ancestor has evolved into two different species, the camel and the llama. This is one example of *divergent evolution*, in which different environmental pressures have led to the evolution of different species from a common ancestor. You can see that this type of divergence over time results in *biodiversity*; that is, it leads to a greater number of species on Earth over time.

Another example of the geographical distribution of species is found in the fauna of Australia. With the exception of two species, one in North America and another in South America, all marsupials are found in Australia. Very primitive mammals, the monotremes are also found only in Australia. Fossil evidence suggests that modern mammals originated in North America. From there, they migrated to Asia, South America, Africa, and Australia. The mammals in Australia became isolated when the land connection in Indonesia went under water in the distant past. As a result, the mammals of Australia diverged in structure from their relatives in other parts of the world. Placental mammals, common on all the other continents, are rare in Australia. The only exceptions were either introduced to the continent by humans or moved to Australia from somewhere else.

In some cases, organisms that are unrelated evolutionarily fill similar niches in similar environments. For example, the polar bear of the North Pole is similar to the leopard seal of the South Pole in that both species are top carnivores in their ecosystems. Similarly, the gazelle in Africa fills a similar niche to that of the white-tailed deer in North America. These are examples of convergent evolution, evolutionarily unrelated organisms filling similar niches in similar but geographically separated environments.

Antibiotic Resistance

Modern medicine provides a good illustration of evolution—how species change over time. Antibiotics are chemicals, isolated or produced by humans, that have the ability to kill harmful bacteria. When a new antibiotic is developed and used, it is typically very successful in killing the target bacterial species. Over time, however, the antibiotic becomes less and less effective as the bacterial species develops resistance to it. So the population of bacteria changes over time. Each individual bacterium is either *resistant* to the antibiotic, in which case it lives, or *not* resistant to the antibiotic, in which case it dies. The point is that the bacteria that are resistant to the antibiotic become increasingly common in the population over time. Therefore, we say that the population has changed over time, which is the definition of evolution used in this course.

Artificial Selection

Humans can "make" populations of organisms change through artificial selection when choosing the particular parental organisms in a genetic cross. There are many examples of this practice, particularly in the field of agriculture. Particular breeds of cattle have been created that display desirable traits, such as a superior ability to produce milk. Particular breeds of dogs are designed to show special traits; for example, border collies are bred for their intelligence and agility. Particular strains of crop plants, such as wheat and canola, are bred for traits such as climate preference or maturation time. Artificial selection is a practice aimed at combining desirable traits seen in two parents. As a result, the traits seen in the population change over time. That is evolution.

What Is the Genetic Connection?

So far in this lesson, you have learned about science and evolution and about how these two ideas are related to each other. But what is the connection between evolution and the principles of genetics, which you studied in the first two modules of this course? As you will learn later in this module, this question has intrigued many scientists, one of whom was Charles Darwin. It also leads to a complex answer that itself continues to evolve as we learn more about the mechanisms of evolution. The genetic connection that exists in the natural world will become clearer through a discussion of some key ideas.

The Nature of Change

Earlier in this lesson, you learned that evolution is defined as the change that occurs in living things over time. The change that occurs can be either structural or functional, and involves *phenotypic change;* that is, the traits that organisms display change in some way over time when evolution occurs.

You learned in Module 1 that phenotype results from genotype and that the genes an organism possesses determine the traits it possesses. The set of genes possessed by an organism is called its genome; therefore, evolutionary change also involves *genotypic change*. Over time, the diversity of the genes possessed by organisms in the population changes when evolution occurs.

Population Genetics

Remember that the genotypic change that occurs as evolution proceeds occurs in the population and not in the individual organism. For example, according to the fossil record, the neck length of giraffes has increased over thousands of years. Each individual adult giraffe has a fixed neck length that cannot be increased, even if a longer neck makes it easier for the giraffe to reach leaves to eat. But the average neck length of the giraffe population can increase over time when a longer neck length gives some advantage to giraffes. That advantage appears to exist because a longer neck does make it easier for giraffes to reach leaves to eat. So, as a result, the genes that result in a longer neck length will, over time, become more common than the genes that result in a shorter neck length.

To look at the complete set of genes in a particular population of organisms that affect a particular trait, means looking at the *gene pool* of that population. Therefore, evolution can be seen as **a change in the composition of the gene pool** of a particular population over time. The genome of each individual organism clearly does not change.

The Time Factor

Keep in mind that the period of time involved in evolutionary change in nature is typically thought to be very long. The term *evolutionary time* is used to imply that the amount of time involved is so much longer than the human life span that it is difficult to comprehend. The change that occurs is both phenotypic and genotypic. It occurs in the population and not in the individual organism and, in general, it takes a long time.

Learning Activity 3.1: Science and Evolution

This learning activity consists of two parts.

Part A

Read each statement below and indicate whether you think it is true or false. If you think a statement is false, change it so that it becomes a true statement.

1. Science has proven that supernatural phenomena do not exist.
2. Scientific theories are clearly proven to be true if the scientific method has been applied correctly.
3. Scientists are certain that evolution occurs.
4. Scientists are certain about how evolution occurs.
5. Divergent evolution is a process that has contributed to the great biodiversity that exists on Earth.

Part B

Match the terms on the left with the correct definitions on the right.

Match	Term
	1. genome
	2. convergent evolution
	3. vestigial structures
	4. gene pool
	5. marsupial
	6. divergent evolution
	7. fossil record
	8. embryology
	9. homologous structures
	10. analogous structures

Definition
A. A pouched mammal; most species are found in Australia.
B. The study of the early development of a species of organism; provides evidence of evolutionary relationship.
C. All the genes possessed by a particular organism.
D. Structures that perform similar functions in organisms that are not evolutionarily related.
E. Occurs when unrelated species become structurally similar because of similar environmental pressures.
F. The total set of genes possessed by a certain population of organisms.
G. Structures that perform different functions in organisms that are evolutionarily related.
H. Structures that are present but serve no apparent purpose, providing a form of evidence for evolution.
I. Occurs when related species become structurally different because of different environmental pressures.
J. Provides many examples of how organisms have changed over time based on their physical remains.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 3.1. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you first learned about the nature of science. Science cannot answer all questions that humans have about the world. Science is a tool that humans have invented to try to understand the world, but it is limited to things that can be experimented with or observed. You have learned that humans have used the tool of science to understand evolution, the genetic change in populations of organisms over time. You have studied various forms of evidence that clearly show that evolution occurs. In addition, you have learned that ideas about the mechanisms of evolution (how it actually occurs) are theoretical; we are always learning more about how evolution occurs through observing the natural world and conducting useful experiments. Finally, you have seen that evolution involves changes in the gene pool of a population of organisms. It occurs over long periods of time.

In the next lesson, you will learn about Charles Darwin's work and the theory of natural selection. Darwin's ideas will provide an introduction to the mechanisms of evolution and how it actually occurs.

Notes

Assignment 3.1: Science and Evolution (20 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 3.

Answer each of the following questions in your own words as clearly as you can in two or three sentences. *(20 marks—4 marks per question)*

1. State and explain something important you learned in this lesson about what *science* means. It can be something that
   - surprised you and resulted in a change in your perspective about science
   - confirmed something important for you that you already knew about science

(continued)

Assignment 3.1: Science and Evolution (continued)

2. State and explain something important you learned in this lesson about what *evolution* means. It can be something that
   - surprised you and resulted in a change in your perspective about evolution
   - confirmed something important for you that you already knew about evolution

3. Explain the following statement:

   It is a fact that evolution occurs, but how it occurs is theoretical.

(continued)

Assignment 3.1: Science and Evolution (continued)

4. Why do we say that evolutionary change occurs when the genetic makeup of the population (as opposed to the genetic makeup of the individual) changes over time?

5. State and explain any two of the forms of evidence for the occurrence of evolution discussed in this lesson.

Notes

Lesson 2: Darwin's Theory of Natural Selection

Lesson Focus

In this lesson, you will

- ❑ describe and explain the process of discovery that led Charles Darwin to formulate his theory of evolution by natural selection

  Include: the voyage of the *Beagle*, Darwin's observations of South American fossils

- ❑ outline the main points of Darwin's theory of evolution by natural selection

  Include: overproduction, competition, variation, adaptation, natural selection, and speciation

- ❑ demonstrate through examples, what the term *fittest* means in the phrase, "survival of the fittest"

  Examples: stick insects blending with their environment, sunflowers bending toward sunlight, antibiotic-resistant bacteria . . .

Introduction

In the first lesson of this module, you learned about the nature of science, the concept of evolution, and the connection that exists between inheritance and adaptation. In this lesson, you will learn about Charles Darwin, the naturalist who explained the mechanism of evolution: natural selection. Remember that science has limitations in terms of the questions it is able to address. Questions dealing with supernatural beings or events lie outside the realm of science. Science attempts to answer human questions about the natural world based on the knowledge gained through experimentation and observation. Keep in mind that we know evolution has occurred and still occurs in the biological world; the mechanism of how it occurs remains theoretical as we seek to understand the natural world.

The Voyage of the *Beagle*

Charles Darwin was born in 1809 in Shrewsbury, England, to Susannah Wedgwood and Robert Waring Darwin, a wealthy society doctor and financier. His grandfather, Erasmus Darwin, was a prominent biologist. Charles was expected from an early age to become a doctor, but his real interests lay in natural history. He enjoyed hiking in the wilderness and observing nature, often collecting plant and animal specimens for his collection. He graduated from Cambridge University with a degree in theology and decided not to continue his expected educational training in medicine.

A painting of Charles Darwin as a young man is shown in Figure 3.3.

Figure 3.3 **Charles Darwin**

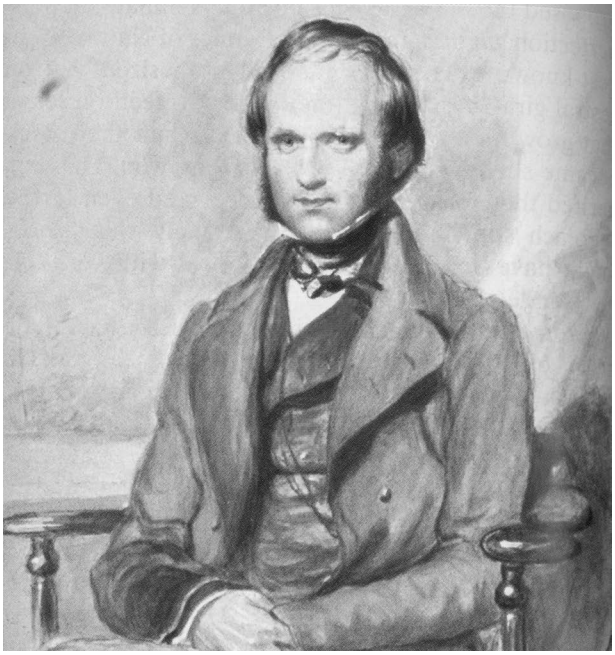


Photo credit: Corbis

Source: Audesirk, Teresa, Gerald Audesirk, and Bruce E. Byers. *Biology: Life on Earth*. 6th ed. Upper Saddle River, NJ: Prentice-Hall, Inc., 2002. 274.

John Henslow, a botanist who shared Darwin's love of natural history, recommended Darwin to Robert FitzRoy, the captain of the HMS *Beagle*, as a companion on the ship's voyage around the world. In 1831, the *Beagle* set sail from England to chart the coast of South America, with Charles Darwin on board as a naturalist.

Before the *Beagle* left England in 1831, FitzRoy gave Darwin a copy of Charles Lyell's book, *Principles of Geology*, which explained landforms on Earth as the result of gradual processes occurring over very long periods of time. During the voyage, Darwin's observations of rock strata, fossil remains, and evidence of tectonic events undoubtedly reinforced his understanding of geologic processes.

The *Beagle* circumnavigated the globe in the five years of its voyage. From England, it travelled to the east coast of South America, around Cape Horn, and north along the west coast of South America. Off the coast of Ecuador, it travelled to the Galapagos Islands, which were briefly discussed in the introduction to this module. Darwin spent much of the time on these islands observing the great diversity of plants and animals on the islands and collecting a vast array of specimens. He studied the famous Galapagos finches, as well as mockingbirds, tortoises, iguanas, and insects. He was amazed by the incredible amount of biodiversity he found there.

From South America, the *Beagle* travelled across the Pacific Ocean to Australia. While there, Darwin discovered marsupials, such as the rat-kangaroo, and monotremes, such as the platypus, that both amazed and puzzled him. They appeared to him to be so different from the mammals of the Americas and Europe that he wondered what their origin could have been. From Australia, the *Beagle* travelled through Indonesia and then southwest to the east coast of Africa. In Cape Town, he met John Herschel, a British astronomer and mathematician who had recently written to Lyell about the "mystery of mysteries"—the origin of species. As the *Beagle* made its way north again to England, Darwin pondered and wrote about his own developing ideas regarding the origin of life on Earth. He also thought about Lyell's suggestions regarding geologic time and plate tectonics.

The voyage of the *Beagle*, which lasted about five years, changed the course of Darwin's life and led to one of the most intriguing biological discoveries ever made. During the voyage, Darwin often sent specimens back to Henslow at Cambridge, including letters about his findings and ideas. In 1836, Darwin returned to England, where he continued to write about and study the observations he made on the *Beagle* voyage. He was a celebrity in England's scientific circles on his return.

The map in Figure 3.4 shows the route taken by the *Beagle* between 1831 and 1836.

Figure 3.4 **Route Taken by the Beagle**

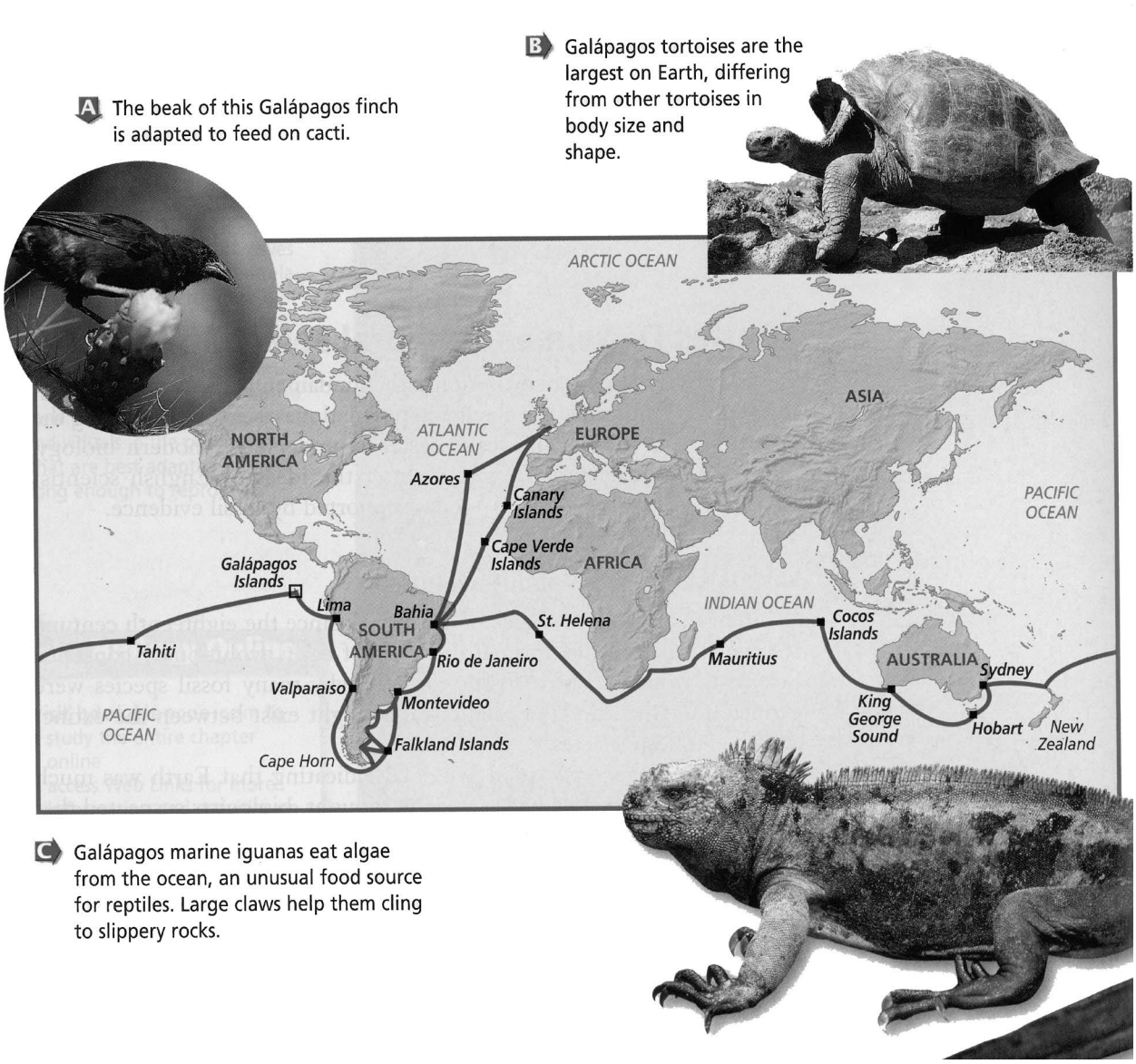


Photo credits: From Lanting/Photo Researchers (top left), Tom Brakefield/DRK Photo (top right), Barbara Cushman Rowell/DRK Photo (b)

Source: Biggs, Alton, et al. *Glencoe Science Biology: The Dynamics of Life.* Columbus, OH: Glencoe/McGraw-Hill, 2004. 394.

Darwin's Return to England

Darwin returned to England in 1836. He spent the next several years compiling the data and classifying the specimens he had collected. During this time, Darwin's father organized investments so that Darwin could work as a "gentleman scientist." Darwin eagerly met Charles Lyell that year to discuss Lyell's work on *uniformitarianism*, the idea that "the present is the key to the past." Lyell introduced Darwin to Richard Owen, a young anatomist who had access to facilities to work on the fossil bones that Darwin had collected during the *Beagle* voyage. Owen identified a number of fossils as belonging to extinct species such as a gigantic sloth and a huge armadillo. The extinct creatures were found to be closely related to living species from South America.

In late 1836 and early 1837, Darwin made presentations in London to the Geological Society, the Geographical Society, and the Zoological Society. The famous ornithologist John Gould identified the species of finches that Darwin had discovered on the Galapagos Islands. During these presentations, the discoveries of Darwin were revealed in the light of Lyell's geological work and in the light of the fossil identifications made by Owen.

In 1837, Darwin moved to London and became a part of its scientific society. Other influential minds in this group included mathematician Charles Babbage, who proposed that God controlled life on Earth by natural laws and not by miraculous bursts of creation. There was also Thomas Malthus, a popular economist who talked about social classes and recommended that people who could not work to support themselves should not be supported by the rest of society. This idea of competition between individuals for necessary resources definitely influenced Darwin's thinking. At this time, also, John Herschel's questions regarding the origin of life on Earth were being hotly debated.

By March of 1837, Darwin clearly became convinced that the animals on the Galapagos Islands had changed in some way over time to become new species on the different islands. You will now look more closely at his developing theory of evolution by natural selection.

The Theory of Evolution by Natural Selection

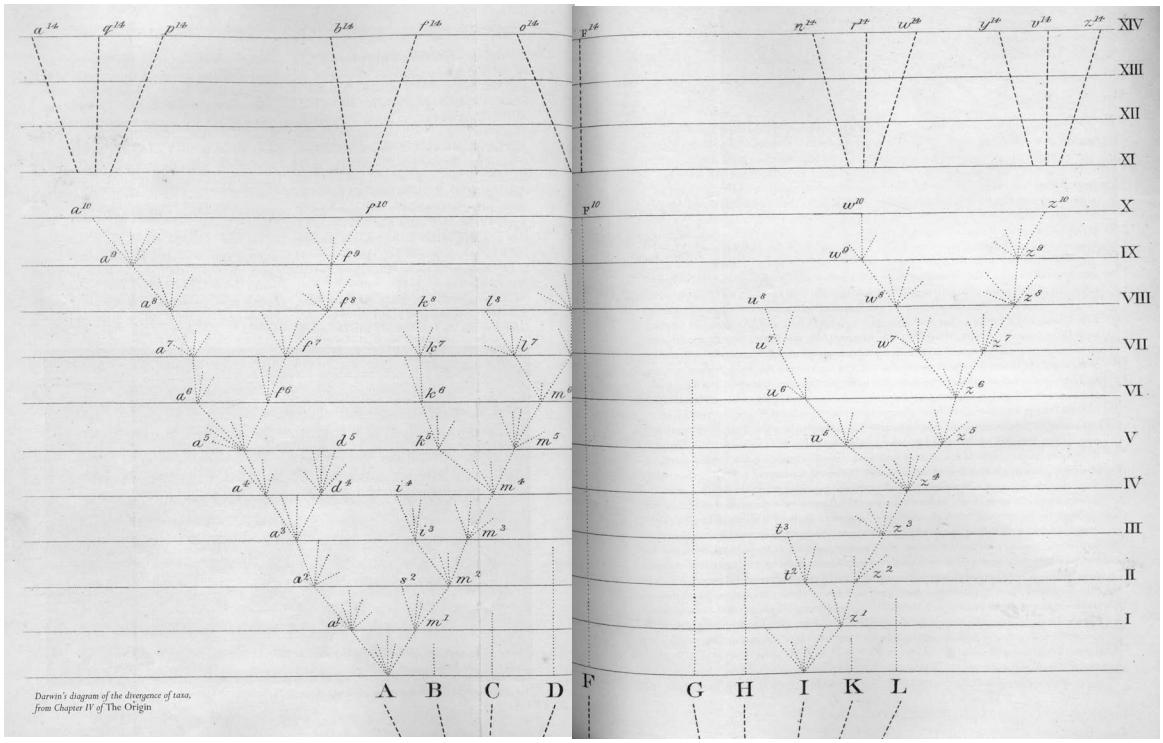
Darwin drafted two manuscripts (in 1842 and 1844) in which he outlined his theory of evolution by natural selection, but withheld them from publication, showing the manuscripts only to trusted friends. Why was Darwin reluctant to publish? Darwin knew his ideas would be controversial and could be perceived as being contrary to the religious teachings of the time, but this was not the main reason for his reluctance to publish. Darwin recognized that there were two main aspects of his theory that were problematic at the time:

- He was unable to explain the origin of the variation within populations that natural selection acted upon.
- He was unable to explain how variation was transmitted from one generation to the next.

In the mid-1850s, Alfred Russell Wallace conceived the same ideas as Darwin, based on his observations in Indonesia. Wallace was considered at the time to be a leading expert on the topic of geographical distribution of species. He was an unconventional thinker who was often at odds with the scientific establishment. Wallace wrote a paper about his ideas and sent it to Darwin to review. This finally spurred Darwin on to agree to the publication of his theory. In 1858, Charles Lyell presented Darwin's 1844 essay and Wallace's paper to the public. Darwin's *On the Origin of Species by Means of Natural Selection* was first published in 1859. The book is a well-constructed argument for natural selection, supported by considerable evidence.

Darwin's diagram of the divergence of taxa shown in Figure 3.5 is a copy of the only drawing that Darwin chose to include in his book. Note how similar it is to the phylogenetic tree you studied in Lesson 1 of this module. Darwin's conceptualization of natural selection and evolution in this way indicates a thorough understanding of change through time.

Figure 3.5 **Darwin's Original Diagram of the Divergence of Taxa**



Source: Darwin, Charles. *On the Origin of Species: The Illustrated Edition*. Gen. ed. David Quammen. New York, NY: Sterling Publishing, 2008. 126–27.

Before you learn more about Darwin's theory of natural selection, you will look at a conflicting theory that was also suggested as an explanation of the mechanism of evolutionary change.

Lamarck's Theory of Evolutionary Change

Decades before Darwin's work was conducted, Jean Baptiste Lamarck was an influential biologist who proposed a mechanism by which organisms change over time. His theory involved the inheritance of acquired traits. Lamarck proposed that during an organism's lifetime it would make small changes to its anatomy or physiology to be more successful in its environment. The organism would then pass these changes on to its offspring. For example, if a wolf benefitted by having a thicker coat of fur to keep it warm during winter, then, as the wolf aged, its fur would gradually thicken. This beneficial change would then be passed on to the wolf's offspring; its pups would be born with fur that was already very thick. According to Lamarck, any organ or structure that was frequently used would become stronger over generations, while an unnecessary structure would weaken and eventually disappear.

Can organisms control what genes they pass on to their offspring, and ensure that the strongest, best, or necessary alleles are always expressed? Today, Lamarck's theory is considered outdated because of current understanding of chromosomes and the relationship between genotypes and phenotypes.

Darwin's Theory of Evolutionary Change

Darwin's theory of evolution by natural selection was presented in his book *On the Origin of Species by Means of Natural Selection*, which was published in 1859. This theory has a great deal of evidence supporting it. Natural selection is no longer believed to be the only mechanism by which evolution proceeds, but it remains the primary theory in biology today.

Darwin's theory of natural selection depends on the following important ideas:

- **Overproduction:** More offspring are produced by an organism than can actually survive.
- **Competition:** Because of overproduction, a shortage of life's necessities leads to competition between members of the same species. These necessities include living space, food, and water.
- **Variation:** Each individual within a species differs from all other members of that species. Some of these differences are very small and some are more profound.
- **Adaptation:** The organisms that are better suited to their environment will survive longer than organisms that are less suited to their environment.
- **Natural selection:** The organisms with the best adaptations will survive and reproduce more successfully than less adapted organisms.
- **Speciation:** New species can form from ancestral species as natural selection proceeds over time.

Keep in mind that Darwin wrote *On the Origin of Species by Means of Natural Selection* before Gregor Mendel's work was published and widely understood. Darwin did not know why variation existed within a population or how traits were passed on from parent to offspring. You will look at that genetic connection again later in this module.

Darwin's theory of natural selection, unlike Lamarck's theory of evolutionary change, does not depend on the inheritance of acquired characteristics. The individual organism, according to Darwin, does not *acquire* traits that better adapt it to its environment. Instead, natural variation is already present in the population; some individuals are naturally better adapted.

Consider, again, the example of wolves. Lamarck proposed that wolves could, through experience, grow a slightly thicker coat of fur to survive winter better. These wolves would pass on their traits to their offspring, so that each generation of wolves would have a progressively thicker and warmer coat of fur and be better adapted to their environment.

The theory of natural selection proposes that, in a given wolf pack, some wolves were born with thick fur coats and others were born with thin fur. The wolves with thin coats might die off more easily during the cold winter months, leaving a majority of wolves with thick coats to reproduce and pass on their genes. The individual wolves would not change during their lifetime, but the entire wolf pack would, over the years, begin to look very different, and be dominated by wolves with thicker fur.

In any population, those individuals best suited to their environment will have a better chance of survival and will reproduce more successfully over time. As a result, the characteristics of the population will change. The genes that cause the beneficial adaptations will become more common in the gene pool. Individual organisms are not themselves changing; populations are changing. That is natural selection.

Survival of the Fittest

Sometimes Darwin's ideas are summarized by the phrase "survival of the fittest"; that is, the best adapted individuals in the population will reproduce more successfully, passing on those genes that yielded the adaptations initially. The best adapted individuals are also called the fittest individuals.

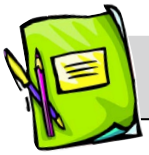
In the context of this course, *fittest* means best able to survive and reproduce successfully. The particular traits that make an organism fit depend on the environment itself. Both biotic (living) and abiotic (non-living) factors are involved in the environmental pressures on a species. The traits that are adaptive in one environment may be detrimental in another. The traits that are adaptive may change over time in one environment as biotic and abiotic factors in it change.

Adaptations can be categorized into the following three groups:

- **Behavioural adaptations:** Some behaviours displayed by some individuals are particularly adaptive; that is, they increase the chance of survival and reproductive success. There are many examples of behavioural adaptations. Seasonal migrations of monarch butterflies, for example, ensure that these insects avoid harsh climates, predation, and lack of food during some parts of the year. Hibernation by bears ensures that they will reduce energy consumption during parts of the year when food is scarce and weather is extreme. Deciduous trees shed their leaves during autumn in temperate climates because those leaves are very vulnerable to cold temperatures and low rainfall during the winter months.

- **Physiological adaptations:** These adaptations are variations in an organism's metabolic processes across a species that allow it to survive and reproduce more successfully. For example, strains of antibiotic-resistant bacteria and pesticide-resistant insects have developed because some individuals naturally possessed adaptations that allowed them to survive in the presence of these chemicals. Those individuals that were adapted survived better and passed that adaptation on to their offspring. Bacterial cells do not individually "learn" to be resistant to antibiotics; however, if a particular bacterial cell is naturally resistant, it will survive and reproduce more successfully, unlike less well-adapted cells.

- **Structural adaptations:** These adaptations affect the shape or arrangement of physical features of an organism. For example, the blowholes of whales and dolphins are relocated nostrils that allow these animals to exhale and inhale from the tops of their heads when they come to the ocean's surface. The needles of cactus plants are actually modified leaves that both protect the plant from grazers and reduce water loss in hot, arid climates. Mimicry is a type of structural adaptation that allows one species to resemble another. The large (up to 75 mm) caterpillar larva of the elephant hawk moth defends itself by mimicking a snake. The swollen segments near the head contain two large "eye spots" that fool insectivorous birds into thinking the organism is dangerous. Camouflage is another type of structural adaptation to the appearance of an organism. The stick insect, for example, resembles the shrub branches that it inhabits. Adaptations such as these assist an organism's chance of survival by allowing it to blend in with its environment.



Learning Activity 3.2: The Theory of Natural Selection

Complete each of the following 15 statements, choosing the correct term (or terms) from the list provided below. Not all terms are used.

List of Terms

adapted	FitzRoy	physiological
Australia	genetics	South America
Beagle	Henslow	speciation
behavioural	Lamarck	structural
biodiversity	Lyell	Titanic
camouflage	Mendel	variation
competition	mimicry	Wallace
fittest	natural selection	Watson

1. The name of the ship on which Charles Darwin travelled to the Galapagos Islands was the _____.
2. The scientist who suggested the theory of uniformitarianism was _____.
3. _____ proposed a theory of adaptation that included the inheritance of acquired traits.
4. The theory that Darwin proposed to explain the mechanism driving evolutionary change is the theory of _____.
5. The friend and mentor of Charles Darwin who encouraged him to travel to the Galapagos was _____.
6. The Galapagos Islands are located off the coast of the continent of _____.
7. Darwin was amazed by the incredible amount of _____ that he found on the Galapagos Islands.
8. The captain of the ship on which Darwin travelled to the Galapagos was _____.
9. Three types of adaptations that exist are _____, _____, and _____.

(continued)

Learning Activity 3.2: The Theory of Natural Selection (continued)

10. Two types of structural adaptations are _____ and _____.

11. One of the important ideas in Darwin's theory is that more offspring are produced in each generation than can survive; this results in _____ between members of the same species.

12. Individuals within the population that possess beneficial traits are said to be well _____ to the environment.

13. Survival of the _____ means that organisms that are well adapted will tend to survive and reproduce more successfully than other organisms.

14. _____ is the development of new species from ancestral species as natural selection continues over time.

15. The man who put forth a theory very similar to Darwin's theory of natural selection was _____.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 3.2. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about the work of Charles Darwin; in many ways, his theory of natural selection served as the foundation on which scientists have since built human understanding of the biological world. Darwin's theory of natural selection provides a mechanism by which evolution occurs. We now know that the mechanism of evolution is actually more complicated than Darwin's original theory suggested. In the following lessons, you will learn more about current knowledge of how evolution occurs.

Assignment 3.2: Theories of Evolutionary Change (20 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 3.

Choose **two** of the following three questions to answer. Answer each of the two questions you have selected in your own words in a short paragraph consisting of at least three to five sentences. Clearly indicate which two questions you have chosen. *(20 marks—10 marks for each question)*

1. Explain Charles Darwin's theory of natural selection. What **two** aspects of his theory did he realize were incomplete and inadequately explained at that time?

2. How did Jean Baptiste Lamarck's theory of the mechanism of evolution differ fundamentally from Charles Darwin's theory of natural selection? What primary flaw do you see in Lamarck's theory, especially considering your study of inheritance in Modules 1 and 2 of this course?

3. What does "survival of the fittest" mean? Name **three** examples from nature that illustrate the meaning of the term *fittest* in a biological sense (give examples that were not cited in this lesson). Briefly explain why you chose **each** example.

(continued)

Assignment 3.2: Theories of Evolutionary Change (continued)

LESSON 3: ADAPTATION

Lesson Focus

In this lesson, you will

- ❑ explain how natural selection leads to changes in populations
  Examples: industrial melanism, antibiotic-resistant bacteria, pesticide-resistant insects . . .
- ❑ describe how disruptive, stabilizing, and directional natural selection act on variation
- ❑ distinguish between *natural selection* and *artificial selection*

Introduction

In the first two lessons of this module, you learned about the nature of science, the principle of evolution, and the theory of natural selection as a mechanism for evolutionary change. In this lesson, you will learn more about adaptation and the meaning of the phrase, "survival of the fittest."

Natural Selection and Adaptation

The following is a brief review of the principal ideas important to Darwin's theory of natural selection:

- A population produces more offspring than the environment can support; some will die or fail to reproduce.
- Competition will occur between the members of the population since not all can survive to reproduce.
- Not all the individuals in the population are identical; natural variation exists within the group.
- The individuals best adapted to the environment will have the best chance of surviving to reproduce. The best adapted individuals are the fittest individuals.
- The genes that caused the well-adapted individuals to survive to reproduce will be passed on to their offspring; therefore, they, too, will be better adapted.
- As a result, over time, the genes carried by the population change and the traits shown in the population as a whole change. Evolution has occurred.

This is a summary of the theory of natural selection as a mechanism for evolutionary change. In this lesson, you will look at three examples of how this process has produced genetic change in natural populations: industrial melanism, antibiotic-resistant bacteria, and pesticide-resistant insects.

Industrial Melanism

The first well-known example in which natural selection has been observed in action is H. B. Kettlewell's study of camouflage adaptation in a population of light-coloured and dark-coloured peppered moths in Manchester, England. *Melanism* refers to the appearance of dark coloration in moths. Remember that genetic diversity naturally exists in populations because of naturally occurring mutations. Mutations are random errors in the genetic code. It is the environmental pressure acting on the population that **chooses** which phenotypes are more beneficial. Individuals possessing those phenotypes are, therefore, more fit. They will reproduce more successfully and will pass those genes on to their offspring, which, as a result, will also be more fit.

The moth in this example is *Biston betularia*, the peppered moth of England. The light-coloured form of the moth was the more common form before the beginning of the Industrial Revolution during the 1800s. The light-coloured moth has speckled wings that camouflage it well against the light-coloured bark of many of the trees common in its range. Predators, especially birds, had a difficult time seeing the moth. However, in the middle of the nineteenth century, a dark-coloured form of *Biston betularia* began to be seen. The first report of this dark variant came in 1848. It is remarkable that, by 1895, the frequency in Manchester of this dark moth reached a documented level of 98 percent of *B. betularia* specimens. The illustration in Figure 3.6 shows both colour variants.

Figure 3.6 **Biston betularia**

Photo credit: M. W. Tweedie/Photo Researchers

Source: Biggs, Alton, et al. *Glencoe Science Biology: The Dynamics of Life.* Columbus, OH: Glencoe/McGraw-Hill, 2004. 397.

The dark-coloured moth was easily seen against a light background; however, it was camouflaged well against a dark background. So, scientists began to investigate the environment in Manchester to gain a better understanding of the change being observed in the moths. In the mid-1800s, as industrialism gained momentum in England, coal-burning became more common. The soot produced by factories blanketed the environment surrounding London, especially between London and Manchester. So, not surprisingly, naturalists at the time concluded that the darker moths had become more common because they were better camouflaged and less obvious to predators.

In recent years, clean air legislation has resulted in a great reduction in soot production in urban areas of England. As expected, the prevalence of the dark-coloured moths has also declined dramatically in those areas. The work done by William Bateson in the 1890s was studied in the 1950s by Kettlewell. Kettlewell found that the dark moths were more common in industrial regions, whereas the light moths were more common in more rural areas. Kettlewell designed experiments in which moths of both colours were released into an aviary so that he could observe and document the predation that occurred. His experimental results validated Bateson's conclusion regarding industrial melanism. Kettlewell also conducted experiments in the field in which he released marked moths and then recaptured them. He clearly demonstrated that natural selection is a force that drives evolutionary change.

Remember that the industrial pollution **did not** itself cause moths to be darker. The dark moths were, because of genetic variation, always in the population. When the environment changed because of industrial pollution, the dark moths had a selective advantage over the light moths. As a result, more dark moths survived to reproduce. Fewer light moths survived to reproduce. The genes causing dark coloration became more common in the population. Evolution had occurred.

Antibiotic-Resistant Bacteria

Have you ever taken antibiotics for an illness, such as strep throat or tonsillitis? When you had the prescription filled, did the doctor or pharmacist remind you to finish all the antibiotics prescribed and not to discontinue taking the antibiotic, even if you started feeling better? Have you ever had to return to the doctor to get a second prescription of a different antibiotic because the first prescription didn't fight the infection?

The case of antibiotic-resistant bacteria has already been referred to earlier in this module. Remember that natural selection operates on the variation already present in a species. It cannot create new structures or processes, contrary to what Lamarck once believed. Variation in antibiotic resistance

occurs naturally within a bacterial population. Some bacteria have a low resistance and are killed when the antibiotic is applied. But some do survive and reproduce, since they are better adapted to the antibiotic-filled environment. With less competition from other bacteria, the resistant bacteria quickly spread.

One well-documented example of such a situation is the case involving *Staphylococcus aureus,* a bacterium that lives on the mucous membranes and skin surfaces of about one-third of the world's population. It was the first bacterium to develop resistance to penicillin; resistance appeared in 1947, only four years after penicillin began to be produced in bulk. The next antibiotic to be used against *S. aureus* was methicillin; however, in 1961, methicillin-resistant *S. aureus* bacteria were found in a British hospital. These methicillin-resistant bacteria were responsible for 37 percent of all fatal blood poisoning cases in 1999 in England. About 50 percent of all *S. aureus* infections in the United States today are resistant not only to penicillin and methicillin, but also to tetracycline and erythromycin. Another more recently developed antibiotic, vancomycin, became the best weapon against this bacterium. However, the first cases of *S. aureus* that were resistant to vancomycin appeared in Japan in 1996; this resistant strain later appeared in England, France, and the United States. Oxazolidinones were a new type of antibiotic that became available in the 1990s. The first *S. aureus* strain resistant to it was reported in 2003. Bacteria such as *S. aureus* that are resistant to a number of antibiotics are sometimes referred to as *superbugs*. This progression of antibiotic resistance in *S. aureus* is shown in Table 3.1.

Table 3.1 **Antibiotic Resistance in *Staphylococcus aureus***

1943	Penicillin is used in bulk to treat bacterial infections.
1947	Strains of *S. aureus* are found that are resistant to penicillin.
	Methicillin is used to combat *S. aureus*
1961	Strains of *S. aureus* are found that are resistant to methicillin.
	Vancomycin is used to combat *S. aureus*
1996	Strains of *S. aureus* are found that are resistant to vancomycin.
	Oxazolidinones are used to combat *S. aureus*
2003	Strains of *S. aureus* are found that are resistant to oxazolidinones.

Humans have not solved the problem of antibiotic-resistant bacteria. Researchers continue to develop new drugs that will fight bacterial infections. But bacteria are so numerous and reproduce so quickly that, even if only a very small number of cells have drug-resistant genes because of natural genetic variation, they spread and become very common in a short period of time. That is evolution by natural selection in action.

Pesticide-Resistant Insects

In modern agriculture, it is important to prevent insect pests from consuming and destroying crops. Unfortunately, the same principles that you just learned about in the case of antibiotic-resistant bacteria also hold true for pesticide-resistant insects. In the natural population of insect pests, some individuals possess a higher tolerance for pesticides than others. Those resistant individuals capable of surviving and reproducing will spread quickly because of reduced competition. The resistant individuals soon outnumber the individuals that can be controlled by pesticide.

This process can be illustrated with an example. In the 1940s, about 7 percent of the crops lost in the United States were lost because of insect pests. In the 1980s, the percentage had jumped to about 13 percent, despite the fact that far more pesticides were used in the 1980s than were used in the 1940s.

Pesticide-resistant insects pose a particular problem to the agricultural industry for a number of reasons. The cost of pesticide research is very high. Also, the agencies that control pesticide use are increasingly careful about permitting the use of new pesticides because of the damaging effects they can have on other species. The case of DDT (dichlorodiphenyltrichloroethane) in the 1960s is a good illustration of this problem.

DDT is a chemical that is inexpensive to produce and is highly effective in killing insect pests. After 1940 it became a primary tool in fighting malaria infections worldwide. In 1948, Paul Muller, the scientist who discovered that DDT could effectively fight insect pests, received the Nobel Prize in Physiology and Medicine; however, in the late 1960s it was found that DDT applied in the environment found its way into the bodies of large birds of prey, such as ospreys and falcons. When female birds of these species produced eggs, their shells were found to be thin and brittle. As a result, the use of DDT was thought to cause a decline in the populations of birds such as the peregrine falcon, which was already a threatened species. In the 1970s in the United States, the use of DDT for all but essential uses was banned.

Types of Selective Pressures

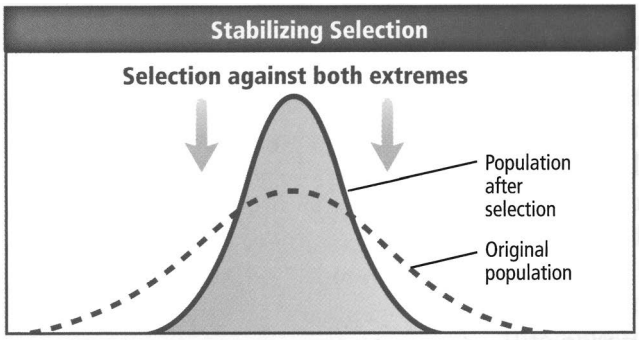
You have now had the opportunity to examine three separate cases of how environmental pressures resulted in genetic change in populations. Next, you will look at three types of selective pressures that can cause genetic change: stabilizing selection, directional selection, and disruptive selection.

Stabilizing Selection

Stabilizing selection favours individuals with an average value for a trait, and selects against those with extreme values. Human birth weight before the practices of modern medicine is an example. Until relatively recent medical advances were made, many infants who were too small did not survive and many infants who were too large died during birth.

Figure 3.7 illustrates a general case of stabilizing selection affecting the distribution of phenotypes in a population. The mid-range phenotypes are favoured by the environmental pressure acting on the population and the low- and high-range phenotypes are selected against. The vertical quantity in this diagram represents frequency of each phenotype. The range of phenotypes, from low to high, is shown on the horizontal axis.

Figure 3.7 **Stabilizing Selection**



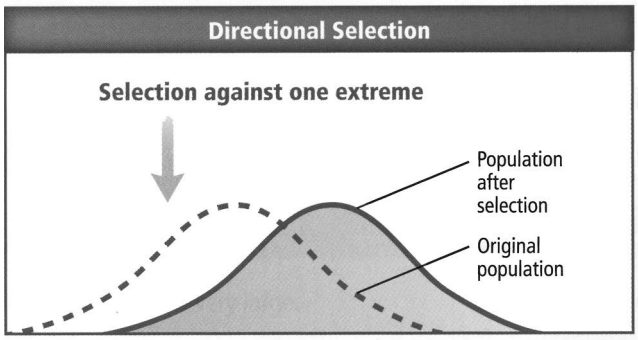
Source: Biggs, Alton, et al. *Glencoe Science Biology.* Columbus, OH: Glencoe/McGraw-Hill, 2009. 434.

Directional Selection

Directional selection favours individuals possessing values for a trait at one extreme of the distribution, and selects against both the average and the opposite extreme. The development of antibiotic-resistant bacteria is an example of directional selection at work. Only those bacteria that can tolerate the presence of an antibiotic survive.

Figure 3.8 illustrates a general case of directional selection affecting the distribution of phenotypes in a population. The phenotypes at the higher end of the range are favoured by whatever environmental pressure is acting on the population. Meanwhile, the phenotypes at the low end of the range are selected against. The vertical quantity in this diagram represents frequency of each phenotype. The range of phenotypes, from low to high, is shown on the horizontal axis.

Figure 3.8 **Directional Selection**



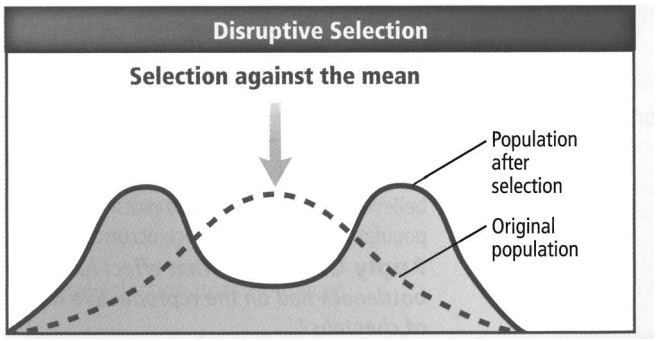
Source: Biggs, Alton, et al. *Glencoe Science Biology.* Columbus, OH: Glencoe/McGraw-Hill, 2009. 434.

Disruptive Selection

Disruptive selection favours individuals at both ends of the distribution and selects against the average. It is also known as *diversifying selection*. Marine organisms called limpets have shell colours that range from white to dark brown. The dark-coloured limpets attached to dark-coloured rocks and the light-coloured limpets attached to light-coloured rocks tend to be less visible to predators and have a higher survival rate than that of intermediate-coloured limpets. The latter are highly visible to predators and are consumed. The intermediate colour is, therefore, being selected against.

Figure 3.9 illustrates a general case of disruptive selection affecting the distribution of phenotypes in a population. The phenotypes at the high and low ends of the range are favoured by whatever environmental pressure is acting on the population. The mid-range phenotypes are selected against. The vertical quantity in this diagram represents frequency of each phenotype. The range of phenotypes, from low to high, is shown on the horizontal axis.

Figure 3.9 ***Disruptive Selection***



Source: Biggs, Alton, et al. *Glencoe Science Biology.* Columbus, OH: Glencoe/McGraw-Hill, 2009. 434.

Natural and Artificial Selection

The final concept to be discussed in this lesson is the distinction made between the forces of natural selection and those of artificial selection. Both forces affect gene pools in both domestic and wild species of organisms on Earth.

Natural Selection

As you have already learned in this lesson, natural selection affects the gene pools of natural populations. The selective forces at work vary with each population, each species, each location, and each environment. Sometimes several selective forces act on a given population at the same time. Whatever selective force acts on the population, individuals that are best adapted (fittest) will survive to reproduce more successfully than other individuals. The example involving peppered moths that you learned about earlier in this module was an example of natural selection at work.

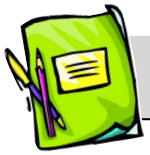
Remember that natural selection does not necessarily lead to perfection in organisms. Natural selection operates on the variation already present in a species; it cannot create new structures or processes. If a phenotype is not already present in a population, it cannot appear because of selective pressures. If having a long neck benefits giraffes because it enables them to reach leaves located higher in trees, then giraffes that already have long necks will survive to reproduce more successfully than giraffes with shorter necks. Giraffes cannot make their necks longer, and then pass that trait on to their offspring. Lamarck's idea of the inheritance of acquired characteristics has not been supported by any experimental or observational evidence. There is, however, a great deal of evidence for natural selection as a mechanism for evolutionary change.

Artificial Selection

In artificial selection, humans ensure that individuals with the more desirable traits are allowed to reproduce. *Artificial selection* is a form of non-random mating and a second cause of change in a population's gene pool. For centuries, breeders have used the natural variation within a population to breed selectively those plants or animals that best represent the properties they wish to see in future generations, such as more productive milk cows, earlier ripening fruits, greater grain yields, and faster racehorses.

An example of artificial selection is found in the many varieties of *Brassica oleracea*, which include broccoli, broccoflower, cauliflower, cabbage, Brussels sprouts, kale, and kohlrabi. All these vegetables have been derived from wild mustard by artificial selection. Another example is found in winter squash. All the varieties of winter squash, including acorn, spaghetti, butternut, Hubbard, and pumpkin, belong to the species *Cucurbita maxima*. All these varieties have been developed using artificial selection.

Lastly, consider the great diversity seen in dogs. Recently conducted genetic studies indicate that the 400 or so breeds of dogs today actually all descended directly from the wolf. Some of this diversification occurred in wild populations of dogs, but most of it occurred because of artificial selection. The first archaeological evidence suggesting that dogs diverged significantly from wolves was found in the Middle East and dates back about 12,000 years. By that time, evidence suggests, dogs were at least partly domesticated by humans. Until the late 1800s, dogs were bred for particular skills, such as hunting rodents (terriers), fetching game (retrievers), and chasing prey (hounds). In the late 1800s, breeding practices began to focus on appearance rather than ability. Registration of purebred dogs also began with the formation of kennel clubs. An example is the Doberman pinscher, which was created as a pure breed in only 35 years in the late 1800s by Louis Doberman of Germany when he crossed German pinschers, Rottweilers, Manchester terriers, and pointers.



Learning Activity 3.3: Adaptation

This learning activity will given you an opportunity to review terms and concepts related to adaptation.

Define each of the following terms:

1. adaptation
2. artificial selection
3. directional selection
4. disruptive selection
5. evolution
6. gene pool
7. genetic variation
8. industrial melanism
9. natural selection
10. stabilizing selection

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 3.3. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned more about the process of natural selection as a mechanism for evolutionary change. You have learned that selection can occur in various ways; stabilizing, directional, and disruptive selection can all affect natural populations. You have also learned about the distinction between natural and artificial selection. In the next lesson, you will expand your understanding of natural selection by looking at how the theories explaining the mechanism for evolutionary change have changed since the time of Darwin and Wallace. Theories about how evolution occurs continue to change with increasing knowledge about the natural world.

Assignment 3.3: Adaptation (15 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 3.

Answer each of the following questions in your own words.

1. Imagine that the modern zebra evolved over the course of thousands of years from a much smaller, dark-coloured ancestor. Explain in a paragraph of three to five sentences how natural selection may have acted on the ancestral zebra to result in the animal that exists today. Be sure to state the particular selective pressures that you think may have acted on this animal. *(5 marks)*

(continued)

Assignment 3.3: Adaptation (continued)

2. Each situation below is an example of stabilizing, directional, or disruptive selection. Explain which one type of selection applies to each of the following five situations. *(10 marks—2 marks for each situation)*

   a) The typical number of eggs found in robin nests if the environment of the birds remains the same.

   b) The beak size of a seed-eating bird in an environment that has undergone serious drought. After the drought, the only plants that were successful in producing seeds were those that produced very small, hard seeds.

   c) The length of a horse's leg bones if modern horses evolved from a tiny ancestor that was built for moving through woodlands and thickets. The modern horse is built for speed on the open grassland.

(continued)

Assignment 3.3: Adaptation (continued)

d) A species of butterfly whose colour varies along a continuum from red to blue to violet. The butterfly habitat is invaded by a flock of insectivorous birds attracted to the colour blue.

e) The length of a monkey's tail if a short tail does not allow the monkey to swing in trees, while a long tail impedes its movement in jungle trees.

Notes

Lesson 4: Population Genetics

Lesson Focus

In this lesson, you will

- ❑ outline how scientists determine whether a gene pool has changed, according to the criteria for genetic equilibrium

  Include: large population, random mating, no gene flow, no mutation, and no natural selection

- ❑ discuss how genetic variation in a gene pool can be altered

  Examples: natural selection, gene flow, genetic drift, non-random mating, mutation . . .

Introduction

You have learned in this module that evolution is the change in living things over time. You are now ready to study the genetic connection—the link that exists between understanding evolution and understanding population genetics. The key idea here is that when organisms evolve, it is the population of organisms that evolves; individual organisms do not evolve. The natural variation that exists in a population because of random mating and mutation provides the raw material on which natural selection can act. Those individuals that are best adapted survive to reproduce more successfully. As a result, the traits seen in the population change over time.

You know from the first two modules of this course that the traits shown by an organism are a direct result of the genes it possesses. Therefore, it is clear that if the traits in a population change over time, then the gene pool in the population also changes. That is the genetic connection that you will study in this lesson, as well as in the next lesson.

Gene Pools

Recall that a *gene pool* is the complete set of genes that determine a particular trait in a particular population of organisms. Recall also that the different forms that a gene can take are called *alleles*. For example, if a gene for fur colour is either *B* for brown fur or *W* for white fur, then *B* and *W* are the two alleles controlling that trait.

When we say that evolution occurs when the gene pool of a population changes, we are saying that the particular alleles present in the population appear in different frequencies relative to each other. In the fur colour example, if an environmental condition begins to favour brown fur for some reason, then the *B* allele will appear with a higher frequency and the *W* allele will appear with a lower frequency over time.

The term *gene frequency* refers to the relative frequencies of the alleles possible for a particular trait. If the *B* allele were present 75 percent of the time and the *W* allele were present 25 percent of the time, then the frequencies could be expressed as the decimals 0.75 (*B*) and 0.25 (*W*). Note that, since these two alleles are the only ones possible for that gene, the sum of their gene frequencies totals 1.00.

The Hardy-Weinberg Principle

The *Hardy-Weinberg principle* is a mathematical model that deals with the frequencies of alleles in a gene pool. This principle states that **the gene frequencies in a population remain constant or are in equilibrium from generation to generation unless specific disturbing influences are introduced**. If the allelic frequency does not change in a population over successive generations, then evolution does not occur, and the population is at *equilibrium*.

Several conditions must be met to maintain this equilibrium:

- No mutation occurs so that the alleles do not change.
- Immigration and emigration do not occur, as they would alter the gene pool and gene frequencies; therefore, no gene flow occurs. Gene flow is the transfer of alleles of genes from one population to another.
- The population must be large so that changes do not happen by chance alone.
- All reproduction must be totally random so that one form of the allele is not selected over another.
- All forms of the allele must reproduce with equal success so that there is no natural selection.

In nature, the idea of genetic equilibrium is an ideal; it serves as a useful model for understanding gene frequencies. As it is virtually impossible to meet these conditions, **allelic frequencies do change** in populations and, therefore, **evolution does occur**. The Hardy-Weinberg principle is useful in explaining why genotypes within a population tend to remain the same, as well as for determining the frequency of a recessive allele.

The Mathematical Tool of the Hardy-Weinberg Principle

The Hardy-Weinberg principle for a population of organisms is sometimes likened to a Punnett square for an individual. The Hardy-Weinberg principle implies a mathematical relationship between gene frequencies in a population that allows us to make useful predictions about how those frequencies change over time.

Consider a scenario where there are two alleles for a given gene. The first allele has a frequency represented by p, while the second allele has a frequency of q. In a population, the sum of the allele frequencies will equal 1.00 (or 100 percent). The first part of the Hardy-Weinberg principle states that the *gene frequencies* in a population can be predicted using this equation:

$\boldsymbol{p + q = 1}$, where

p = frequency of the first allele

q = frequency of the second allele

In this example, there are only two alleles for the gene in question. Keep in mind that one allele may be dominant and the other recessive, or that neither allele may be dominant over the other.

The Hardy-Weinberg principle also states that frequencies of individual genotypes can be calculated using the gene frequencies p and q. Remember that each diploid individual has two alleles for every gene—one from each parent. So, an individual with two alleles of the first type, which has gene frequency p, will exist in the population with a frequency of $p \cdot p$ or p^2. That is because in statistics, if the probability of Event A occurring is a (which is a decimal between 0 and 1) and the probability of Event B occurring is b (which is a decimal between 0 and 1), then the probability of Event A *and* Event B occurring is $a \cdot b$, the *product* of their individual probabilities:

$P(a) = 0.5$

$P(b) = 0.5$

$P(a \text{ and } b) = P(a) \times P(b) = 0.5 \times 0.5 = 0.25$

So, if the probability of receiving a certain allele is p, then being homozygous for that allele has a probability of p^2.

Following that statistical rule, an individual with two alleles of the second type, which has gene frequency q, will exist in the population with a frequency of $q \cdot q$ or q^2. An individual with one allele of each type will exist in the population with a frequency of $p \cdot q$ or pq. Therefore, the second part of the Hardy-Weinberg principle states that the **genotype frequencies** in a population can be predicted using this equation:

$\boldsymbol{p^2 + 2pq + q^2 = 1}$, where

p^2 = frequency of individuals homozygous for allele 1

q^2 = frequency of individuals homozygous for allele 2

$2pq$ = frequency of heterozygous individuals

The reason the heterozygous genotype has a frequency of $2pq$ instead of just pq is that, using the fur colour example again, a heterozygous individual can be either *BW* or *WB*. You can also create a Punnett square for the two allele frequencies, p and q, as shown in Figure 3.10.

Figure 3.10 **Punnet Square**

	p	q
p	pp	pq
q	pq	qq

In the above Punnett square, only one combination of alleles will produce *pp* offspring. On the other hand, there are two combinations of alleles that will produce a heterozygous *pq* offspring. Both of these combinations must be accounted for when calculating allele frequencies.

You will now look at two examples of how the Hardy-Weinberg principle can be applied.

Example 1

Free earlobes are caused by a dominant allele (*E*), while attached earlobes are due to the recessive allele (*e*). In a classroom population of 20 students, 15 students have free earlobes and 5 have attached earlobes.

1. Determine the frequency of the recessive allele.
   - You know that $\frac{5}{20}$ students are *ee* (homozygous recessive).

     $\frac{5}{20} = 0.25$
   - Next, find out how frequently at least one *e* allele appears in the population's genotypes.
   - In the equation ($p^2 + 2pq + q^2 = 1$), you know that $q^2 = 0.25$.
   - If you take the square root of q^2, you will find the value of $q \cdot q$ represents the frequency of one *e* allele in the population.
   - $\left(\sqrt{q^2}\right) = \left(\sqrt{0.25}\right) = (0.50)$

   The frequency of the recessive allele is 0.50.
2. Determine the frequency of the dominant allele using the equation $p + q = 1$.
   - In question 1, you found that $q = 0.50$.
   - Because $1 - q = p$, the frequency of the dominant allele is 1 – 0.50 or 0.50.

   The frequency of the dominant allele is 0.50.
3. Determine the frequency of individuals homozygous for the dominant allele (p^2).
   - In question 2, you found that $p = 0.50$.
   - You know the probability of having one dominant allele (*p*); now you must find the probability of having two dominant alleles (*pp*).
   - $p^2 = (0.50)^2 = 0.25$

   The frequency of individuals homozygous for the dominant allele is 0.25.
4. Determine the frequency of heterozygous individuals ($2pq$).
   - $p = 0.50$, and $q = 0.50$
   - $2pq = 2(0.50)(0.50) = 0.50$

   The frequency of heterozygous individuals is 0.50.
5. Check calculations using the Hardy-Weinberg equation ($p^2 + 2pq + q^2 = 1$).
   - *Sample data:* $0.50^2 + 2(0.50)(0.50) + 0.50^2 = 0.25 + 0.50 + 0.25 = 1$

This example illustrates how a recessive gene may appear frequently throughout a population, even though the number of homozygous recessive individuals is quite low.

Example 2

In some areas of Africa, the recessive sickle-cell anemia allele has a frequency of 0.30.

1. What is the frequency of the normal allele?
   - Assuming there are only two alleles, you can use the equation ($p + q = 1$) to find the frequency of the normal allele (p).
   - The recessive allele, q, has a frequency of 0.30.
   - $p + 0.30 = 1$
   - $p = 1 - 0.30$
   - $p = 0.70$

   The frequency of the normal allele is 0.70.

2. You can use the above data to illustrate the Hardy-Weinberg equation:

   ($p^2 + 2pq + q^2 = 1$), where

   p^2 = frequency of individuals homozygous for the dominant allele

   q^2 = frequency of individuals homozygous for the recessive allele
   - $2pq = 2(0.70)(0.30) = 0.42$

     42% of the population carries the gene for sickle-cell anemia, but is not affected by the disorder.
   - $q^2 = 0.30^2 = 0.09$

     9% of the population is affected by sickle-cell anemia.
   - $p^2 = 0.70^2 = 0.49$

     49% of the population is not affected by sickle-cell anemia, and does not carry the gene.

3. You can also put these three frequencies into the original equation to verify whether they are accurate.
   - $p^2 + 2pq + q^2 = 1$
   - $0.49 + 0.42 + 0.09 = 1$

   The genotype frequencies are accurate.

These calculations allow you to determine that although a relatively small percentage of individuals (9 percent) in the population are affected by sickle-cell anemia, the recessive allele is widely distributed in the population. In fact, 51 percent of the population carries at least one copy of the sickle-cell allele. This illustrates why recessive alleles are not removed from a population, even though the number of individuals with the homozygous recessive condition may be quite low.

Change in Gene Frequencies

You have just learned how the Hardy-Weinberg principle can be used to understand allele frequencies in a population. Remember that the principle is based on a number of assumptions and that these assumptions are virtually never true in nature. Nevertheless, the Hardy-Weinberg principle is a useful model for understanding complex natural processes.

You will now look at real natural populations and consider how they usually **do not conform** to the assumptions of the Hardy-Weinberg principle:

- Natural selection affects variations that naturally exist in a population, as the better adapted (more fit) individuals survive and reproduce more successfully, passing their genes on to their offspring.
- Immigration and emigration of individuals from a population will affect allele frequencies and, therefore, gene flow.
- The change in the gene pool of a small population due to random chance is called *genetic drift.* The *bottleneck effect* is a form of genetic drift that results from the near extinction of a population. The *founder effect* is a form of genetic drift that results from a small number of individuals colonizing a new area. In both cases, allele frequencies can change dramatically.
- In animals, *non-random mating* often occurs, as the choice of mates is often an important part of behaviour (e.g., courtship rituals). Many plants self-pollinate, which is a form of inbreeding or non-random mating.
- Mutations occur constantly. They provide the source of new alleles, or variations upon which natural selection can take place.

You will now take a closer look at the bottleneck effect and the founder effect.

The Bottleneck Effect

Population bottlenecks occur in a population when its size is dramatically reduced for at least one generation. A significant reduction in population means that 50 percent or more of the population is either killed or is otherwise prevented from reproducing. This can occur for many different reasons in natural populations.

The European bison, also called the wisent, became nearly extinct in the early 1900s. The animals from this species that are alive today have descended from only 12 individuals. Therefore, the population today has extremely low genetic variation. As the population grows, its genetic variation is expected to rise gradually due especially to random mutation.

Another example is the cheetah. Skin grafts from one cheetah to another do not cause pronounced immune responses in the recipient animals, presumably because the two individuals are genetically so similar to each other. This fact suggests that in the past a significant population bottleneck probably occurred in this species. It is noteworthy that selective breeding (artificial selection) practices that are conducted to produce pure lines of dogs, cats, horses, and many other kinds of animals are actually creating bottlenecks for those species. Breeders limit the gene pools of these organisms based on desired appearances, abilities, or both.

The Founder Effect

The *founder effect* occurs when only a few members of the original population separate to form a new colony. This new colony shows reduced genetic variation compared to the original population. The individuals that strike out to form the new colony may not be a random sample of individuals and, therefore, may not possess a random sample of the genes in the original population.

For example, the Afrikaner population in South Africa was originally started by a small number of Dutch colonists. As a result, traits common in that small population are common in the larger population that descended from them. The gene that causes Huntington disease was present in the small number of colonists who started the Afrikaner population in South Africa; therefore, Huntington disease is more common now in the population there than it is in the original Dutch population today.

Learning Activity 3.4: Population Bottlenecks and Endangered Species

Read about the whooping crane population below, and then use the information provided to answer the questions that follow.

The Whooping Crane

The whooping crane (*Grus americana*) is the tallest bird in North America, standing almost 1.5 m in height, with a wingspan of up to 2.5 m. Whooping cranes are an endangered species that nest in the Wood Buffalo National Park of the Northwest Territories.

While populations of "whoopers" were never large, their numbers declined rapidly in the early 1900s from hunting and habitat destruction due to agriculture. In 1941, only about 15 whooping cranes were left in the world. In the 1940s, various agencies in Canada and the United States joined in an effort to save the birds from extinction.

Wildlife refuges and national parks now protect the whooping crane's natural summer breeding area in the Northwest Territories and wintering grounds in coastal Texas. Captive breeding programs have been established in some zoos, including the Calgary Zoo. Other flocks have been established in Florida (non-migratory) and Wisconsin (migratory). By the winter of 2008/09, the whooping crane population had climbed to 534 captive and wild birds, 247 of which nest in Wood Buffalo National Park. All the Wood Buffalo birds today are descended from the 15 migratory birds of 1941.

Conservation efforts are hampered by a number of factors. About 15 percent of eggs laid in the wild are infertile, possibly as a result of inbreeding. The success rate of nesting pairs successfully producing a chick is only about 50 percent. Disease is a problem in some captive breeding populations. Severe climatic events, including hurricanes in Texas and late-spring blizzards in the Northwest Territories breeding grounds, can lead to increased mortality. Predation of newly hatched chicks is always a threat. Power lines and cell towers pose hazards during migration. Habitat disturbance in the Texas wintering grounds is an ongoing concern due to shipping and oil exploration and development. While their numbers have increased due to conservation efforts, whooping cranes are still threatened with extinction.

(continued)

Learning Activity 3.4: Population Bottlenecks and Endangered Species (continued)

References

Alberta Sustainable Resource Development. "Alberta's Whooping Crane." *Species at Risk Fact Sheets*. May 2003. www.srd.alberta.ca/BioDiversityStewardship/SpeciesAtRisk/SpeciesSummaries/documents/Whooping_Crane_May03.pdf (Oct. 21, 2010).

Kuyt, E. "Whooping Crane." Rev. 1993. *Hinterland Who's Who*. Canadian Wildlife Service and Canadian Wildlife Federation. 2003. www.hww.ca/hww2p.asp?id=79&cid=7 (Oct. 21, 2010).

Questions

1. Whooping cranes are an example of an endangered species that has passed through a population bottleneck. Explain how a population bottleneck can alter the genetic variation in the gene pool of a species.
2. How does a population bottleneck affect the ability of a species, such as the whooping crane, to evolve and adapt to environmental changes?
3. How could the population bottleneck affect the ability of the whooping cranes to recover from near extinction?
4. Why should people try to protect and conserve an endangered species?

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 3.4. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned several principles of population genetics. You have also learned more about the genetic connection that was referred to earlier in this module. In the final lesson of this module, you will learn about how the genetic change that occurs in populations can actually lead to populations becoming genetically distinct from other populations of the same species. Understanding this kind of population separation at a genetic level will help you to understand how new species are thought to develop from existing species—another piece of the evolution puzzle.

Assignment 3.4: Population Genetics (22 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 3.

Answer each of the following questions in your own words.

1. A geneticist discovers a flower that has two colour variations, red and blue. It is known that this is a dominant/recessive trait involving two alleles. When two blue flowers are crossed, they always produce blue flowers. When two red flowers are crossed, they produce red flowers and sometimes blue flowers. Counting the flowers reveals that 510 flowers are red and 490 are blue. **Clearly show your calculations and your final answer to each of the following questions.**
   (14 marks—2 marks per question)

   a) Which flower colour is dominant? Explain your thinking.

   b) What proportion (expressed as a decimal) of flowers are blue?

   c) What is the frequency of the gene for blue flowers in this population?

   d) What is the frequency of the gene for red flowers?

(continued)

e) What is the percentage of homozygous dominant individuals in the population?

f) What is the percentage of heterozygous individuals in the population?

g) What is the percentage of homozygous recessive individuals in the population?

2. Explain the meaning of **each** of the following equations that make up the Hardy-Weinberg principle. Be sure to explain what the letters used stand for and why each equation is true. *(6 marks—3 marks per question)*

   a) $p + q = 1$

(continued)

Assignment 3.4: Population Genetics (continued)

b) $p^2 + 2pq + q^2 = 1$

(continued)

Assignment 3.4: Population Genetics (continued)

3. The Hardy-Weinberg principle states that if the allelic frequency does not change in a population over successive generations, then evolution does not occur and the population is at *equilibrium*. Several conditions must be met to maintain this equilibrium:
   - No mutation occurs so that the alleles do not change.
   - Immigration and emigration do not occur as they would alter the gene pool and gene frequencies; therefore, no gene flow occurs. Gene flow is the transfer of alleles of genes from one population to another.
   - The population must be large so that changes do not happen by chance alone.
   - All reproduction must be totally random so that one form of the allele is not selected for over another.
   - All forms of the allele must reproduce equally well so that there is no natural selection.

   Explain why we continue to use the Hardy-Weinberg principle to understand population genetics, when the assumptions on which the principle is based are **not** true in natural populations. *(2 marks)*

Lesson 5: Evolution and Speciation

Lesson Focus

In this lesson, you will

- ❑ describe how populations can become reproductively isolated
  Examples: geographic isolation, niche differentiation, altered behaviour, altered physiology . . .
- ❑ with the use of examples, differentiate between *convergent evolution* and *divergent evolution* (adaptive radiation)
- ❑ distinguish between the two models for the pace of evolutionary change: punctuated equilibrium and gradualism

Introduction

In May 2006, a white bear with brown patches was found dead in the Northwest Territories. DNA tests later confirmed that the bear was the offspring of a male grizzly bear and a female polar bear. It was the first grizzly-polar hybrid bear found in the wild. The hybrid animal has been named a grolar bear or a pizzly. Aren't polar bears and grizzly bears separate species? If they are, why can they produce offspring?

Returning to the example of Darwin's finches on the Galapagos Islands, why did Darwin find species on the islands that, while they were all finches, differed so significantly from the finches on the mainland and from each other? There is no evidence that the species of finches on the Galapagos Islands cross-breed to produce hybrid species. But if they are all finches, is hybridization possible? Why are the finch species on the Galapagos different from the finch species on the mainland?

In this lesson, you will investigate how different populations of the same species can sometimes become so different from one another that they can no longer interbreed. You will also study patterns of evolution—how organisms are thought to change over time. Darwin's theory of natural selection is the foundation on which you will build this understanding.

Reproductive Isolation

When a part of a population becomes reproductively isolated from the parent population, it can become so different that it becomes a separate subspecies or even a separate species over time. A *subspecies* is a subset within a species; members of the same species that belong to different subspecies can still mate to produce fertile offspring. The distinction here is that members of two different *species* may be able to reproduce, but their offspring will be infertile. For example, the horse and the donkey belong to two different species. When sperm from a donkey fertilizes a horse egg cell, they produce a mule; mules are reproductively infertile. Two mules cannot produce offspring; neither can a cross between a mule and a horse or a mule and a donkey produce offspring. So, when we refer to reproductive isolation, we are referring to different populations of the same species for some reason being unable to interbreed for some time. Sometimes this separation does not lead to major differences between the two populations. In some cases, however, this separation leads to the two populations becoming very different from one another; a new subspecies or even a new species may be the result. The development of a new species is called *speciation*.

Reproductive isolation can occur in a number of ways, including geographic isolation, niche differentiation, altered behaviour, and altered physiology.

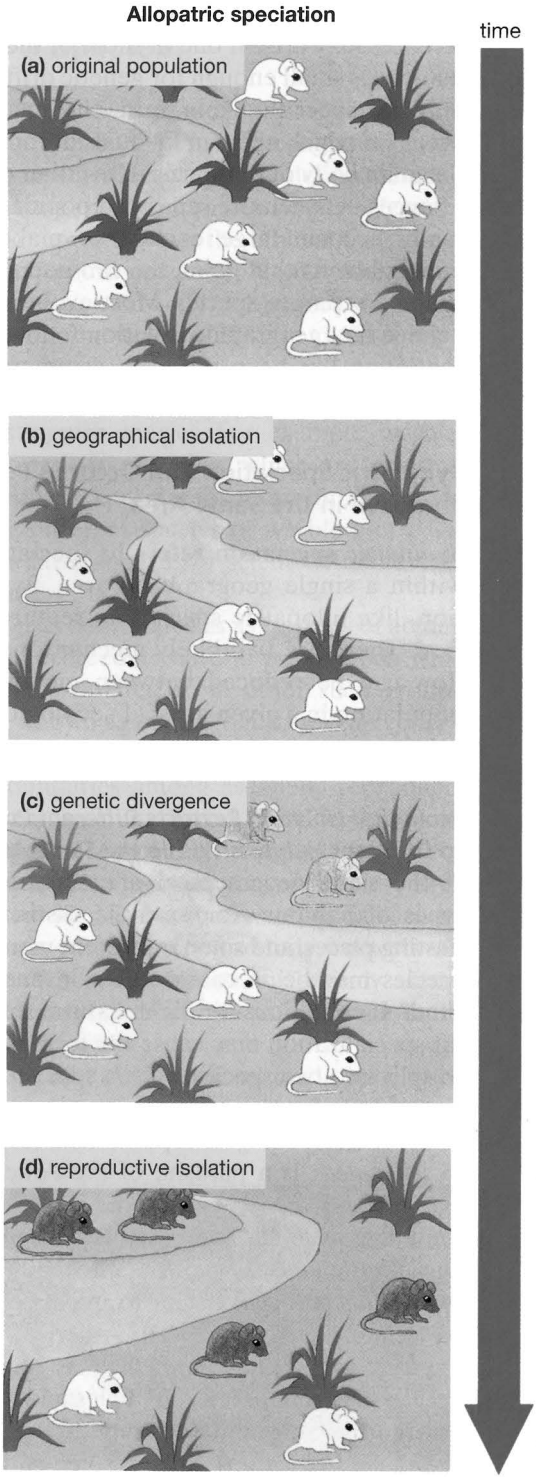
Geographic Isolation

When part of a population becomes geographically isolated from the parent population, speciation can occur. This type of geographic speciation is also called *allopatric speciation*. It may occur due to the formation of physical barriers, such as mountains, canyons, rising sea levels, or glaciations. The physical barriers prevent gene flow between the two populations. If the isolated populations are subjected to different natural selection pressures, the traits that are beneficial to possess also become different. Those traits that define which individuals are fittest are genetically determined. So, over time, gene frequencies will change. The two populations may accumulate substantial genetic differences; if individuals of the two groups later come in contact with one another, they may be unable to interbreed. Two distinct species are the result.

Darwin's finches provide a good example of allopatric speciation. When the finches on the Galapagos Islands are compared to those of the mainland, it is apparent that they are all finches and are related; however, the birds on the islands are so different from the birds on the mainland that they are classified into different species. No island finch species exists on the mainland and no mainland finch species exists on the islands. Speciation has occurred due to geographic isolation.

Consider the diagram illustrating allopatric speciation in Figure 3.11.

Figure 3.11 **Allopatric Speciation**



Source: Audesirk, Teresa, Gerald Audesirk, and Bruce E. Byers. *Biology: Life on Earth*. 6th ed. Upper Saddle River, NJ: Prentice-Hall, Inc., 2002. 310.

In this illustration, you see a population of mice separated into two groups by a river. The two groups of mice are totally reproductively isolated from each other. Over time, the two groups of mice become different from one another. They are so different, in fact, that the two groups cannot interbreed even when the physical barrier, the river, is no longer separating them. Speciation has occurred.

Niche Differentiation

An organism's *niche* refers to the role it plays in its environment. It includes many aspects of the ecology of an organism: its diet, predators, competitors, behaviour, mating habits, geographic range, and physical traits. Sometimes an organism's niche is said to be the way it "makes a living" in its environment. When the gene flow between members of a population is restricted due to *ecological isolation*, niche differentiation may be the result. In this case, this process is called *sympatric speciation*.

Some members of a population may naturally be better adapted than others to a slightly different niche in an ecosystem and may begin to specialize in that niche. For example, a small group of individuals may begin to hunt on the edge of the forest instead of within the forest. Those two habitats are parts of different niches; different niches involve different selective pressures. Because different traits will be favoured, genetic changes will occur over time. The two populations become reproductively isolated because of the different niches that they fill. Genetic differences accumulate over time and speciation is the result.

An example can help illustrate sympatric speciation. A few centuries ago, a species of maggot flies laid their eggs on hawthorn trees, found in North America. Immigrants from Europe introduced domestic apple trees to the environment, and some of the maggot flies began to lay their eggs on the apple trees instead of on hawthorn trees. The flies that hatched on hawthorn trees tended to reproduce on hawthorn trees, and the flies that hatched on apple trees later tended to reproduce on apple trees. So, the gene flow was reduced between the two parts of the population that mated on different types of fruit trees. After about 200 years, significant genetic differences already exist between these two groups of flies. It is thought that these maggot flies provide an example of sympatric speciation in action. In this example, flies that lay eggs on apple trees reproduce about six weeks before flies that lay eggs on hawthorn trees. The two groups of flies fill two different niches, and are reproductively isolated from each other as a result. (You will learn more about the maggot flies in Lesson 2, Module 4.)

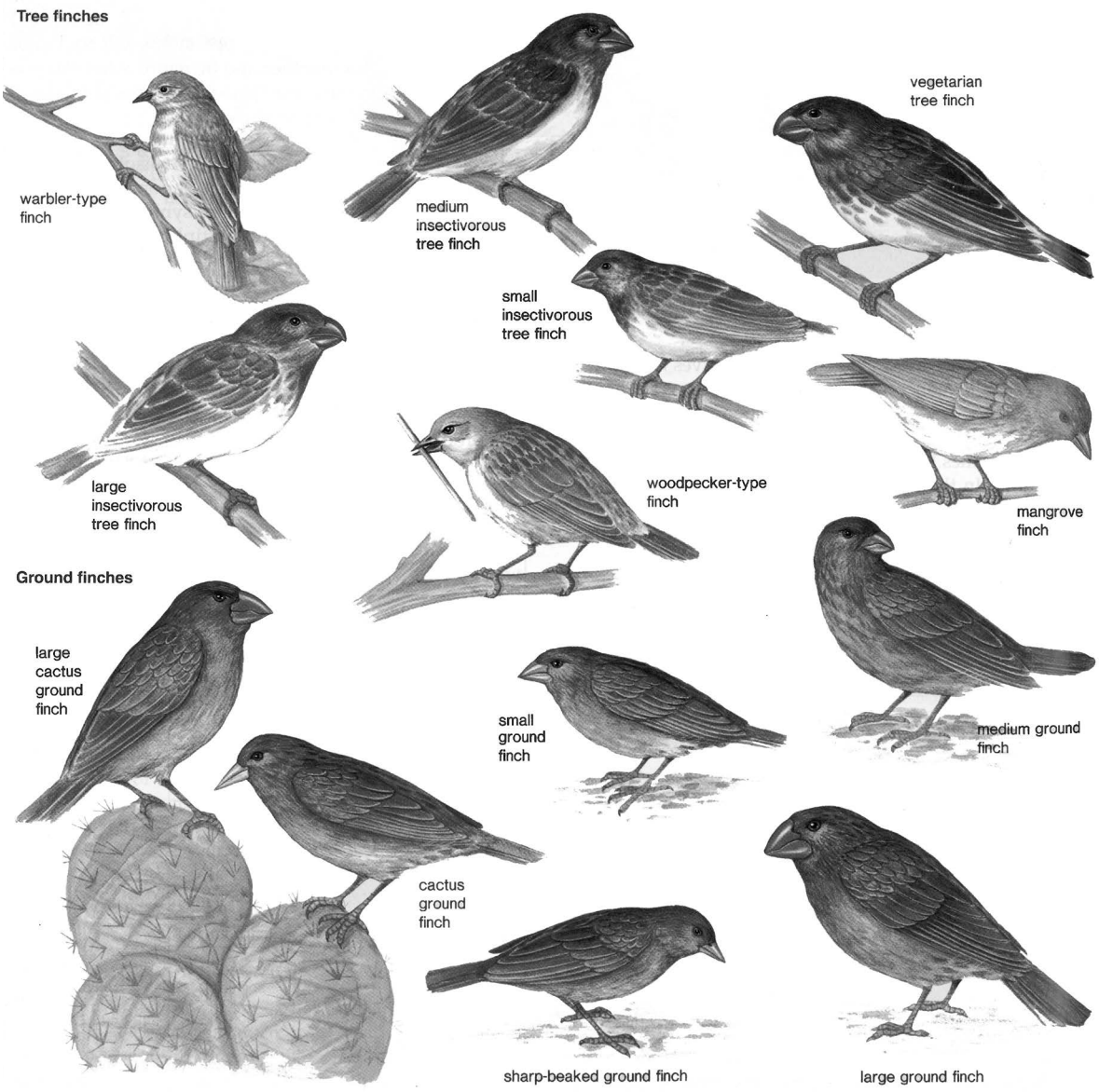
Altered Behaviour

Alterations in behaviour can also lead to reproductive isolation. Should a group of nocturnal mammals become active during the day, they may no longer interbreed with their counterparts who are active at night. A good example of this process is the evolution of mating behaviour. If a small group of organisms within a population develops different mating behaviours that the members of the original population do not practise or recognize, the small group may become reproductively isolated from the larger group. Different physical displays, songs, and calls are all examples of mating behaviours that can change to result in reproductive isolation. Mating behaviour may involve aggressive displays or submissive actions that are necessary for successful mating to occur. These mating rituals ensure that two fit individuals of the same species will come together to mate successfully. If the behavioural requirements are not met, the two individuals do not breed.

Altered Physiology

Another mechanism of reproductive isolation is altered physiology. If a group within a population develops a physiological difference from the rest of a population, the two groups may no longer interbreed. Coloration, size, and physical features are all examples of physiological characteristics. Consider the finches Darwin discovered on the Galapagos Islands; there are remarkable differences in the sizes and shapes of their beaks, as shown in Figure 3.12. These physical characteristics enable the birds to eat different types of food and, therefore, to display different behaviours. The birds have become different enough that they no longer interbreed, and belong to different species.

Figure 3.12 **The Galapagos Finches**



Source: Mader, Sylvia S. *Inquiry into Life*. 11th ed. New York, NY: McGraw-Hill, Higher Education, 2006. 564.

Evolutionary Patterns

It is useful to distinguish between two primary patterns in the course of evolutionary change: *divergent evolution* and *convergent evolution*. Recall that *diverge* means to extend or move in different directions from a common point, and that *converge* means to come together or move toward a common point.

Divergent Evolution

Divergent evolution, also referred to as *adaptive radiation*, occurs when related species become structurally different because of different environmental pressures. The finch species on the Galapagos Islands presumably evolved from an ancestral stock from the mainland. Because a diversity of foods was present on the islands, small groups of birds started to specialize in eating different types of food. As a result, over time, the groups *diverged* from one another. They became so dissimilar that they could no longer interbreed and, therefore, became different species.

When we look at organisms that have experienced divergent evolution, we see structures that perform different functions in different organisms that are thought to have evolved from a common ancestor. For example, whales and dogs are both mammals and are, therefore, related. The bones of their forelimbs are similar in structure but are used for very different purposes. The whale has adapted to a marine environment, while the dog has adapted to a terrestrial environment.

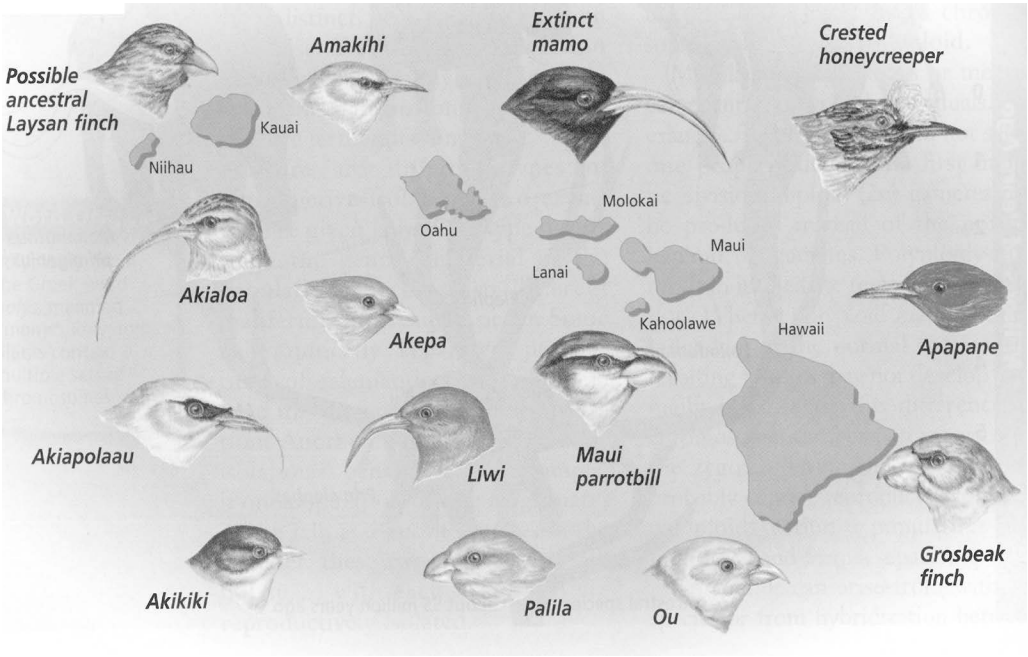
In divergent evolution, an ancestral species gives rise to a number of new species that are adapted to different environmental conditions. This often occurs when a species colonizes a new environment in which there are unoccupied ecological niches.

Further examples of divergent evolution in action are provided by the red fox and the kit fox and by Hawaiian honeycreepers:

- **The red fox and the kit fox:** These two species are believed to have evolved from a common ancestor. The two groups have diverged from one another over time because they fill different niches and live in different habitats. The red fox inhabits mainly forests and farmland; its red coloration helps it to blend into the foliage and environment. The kit fox lives in desert and prairie environments where its grey coloration helps it to blend in with its environment. The kit fox also has larger ears than the red fox. The larger surface area of the kit fox's ears enables it to get rid of excess body heat in the dry environments that it inhabits.

- **Hawaiian honeycreepers:** These birds fill a great diversity of niches. Some have finch-like bills, while others have long, slender, down-curved bills for probing flowers. There are about 20 known forms of Hawaiian honeycreepers. Consider the illustration in Figure 3.13.

Figure 3.13 **Hawaiian Honeycreepers**



Source: Biggs, Alton, et al. *Glencoe Science Biology: The Dynamics of Life*. Columbus, OH: Glencoe/McGraw-Hill, 2004. 412.

Convergent Evolution

Convergent evolution is the process in which different organisms that live in similar habitats become more alike in appearance and behaviour. As they encounter similar environmental pressures, the organisms develop *analogous structures*—structures that have adapted to perform similar functions in unrelated organisms. For example, dolphins and sharks live in the ocean and both use their tails for propulsion. However, their tails are analogous structures with different origins. Sharks move their tails side to side, while dolphins move their tails up and down. Similarly, bat, butterfly, and bird wings are analogous structures. The three animals are very unrelated but have developed a similar adaptation to the environment that they inhabit.

Examples of convergent evolution are provided by the following animals:

- **Antelope and kangaroo:** Antelope are plains animals adapted to dry, open environments. The pronghorn antelope lives in North America and forms herds on the open plains. In Australia, the kangaroo fills a similar niche. The antelope and the kangaroo are not closely related, but they do share a number of physiological and behavioural similarities because they share similar niches on two different continents.
- **Anteaters, aardvarks, and echidnas:** Several mammalian species have evolved long claws on their forelimbs and long, sticky tongues that enable them to open the homes of small colonial insects such as ants and termites and then eat them. There are four species of anteaters, more than a dozen species of armadillos, eight species of pangolins, an African species of aardvark, the Australian echidna, and the Australian numbat. Not all these species are related to one another, but they show an amazing similarity of form and behaviour. They fill a similar niche in their respective habitats. Consider pictures of two of these species in Figure 3.14.

Figure 3.14 ***Anteater and Echidna***

The Pace of Evolutionary Change

When we say that organisms change over time, we do not specify how quickly they change. Theories about how evolution occurs continue to be refined and expanded as our knowledge of biology grows. In other words, these theories themselves continue to evolve.

Two Approaches to the Pace of Evolutionary Change

In Charles Darwin's time, it was presumed that organisms change gradually over long periods of time. Since Darwin's time, however, thinking on this topic has changed. You will now look at two different views of the pace of evolutionary change: gradualism and punctuated equilibrium. Note that most evolutionary biologists believe that some aspects of both models occur during the evolutionary history of a species.

Gradualism

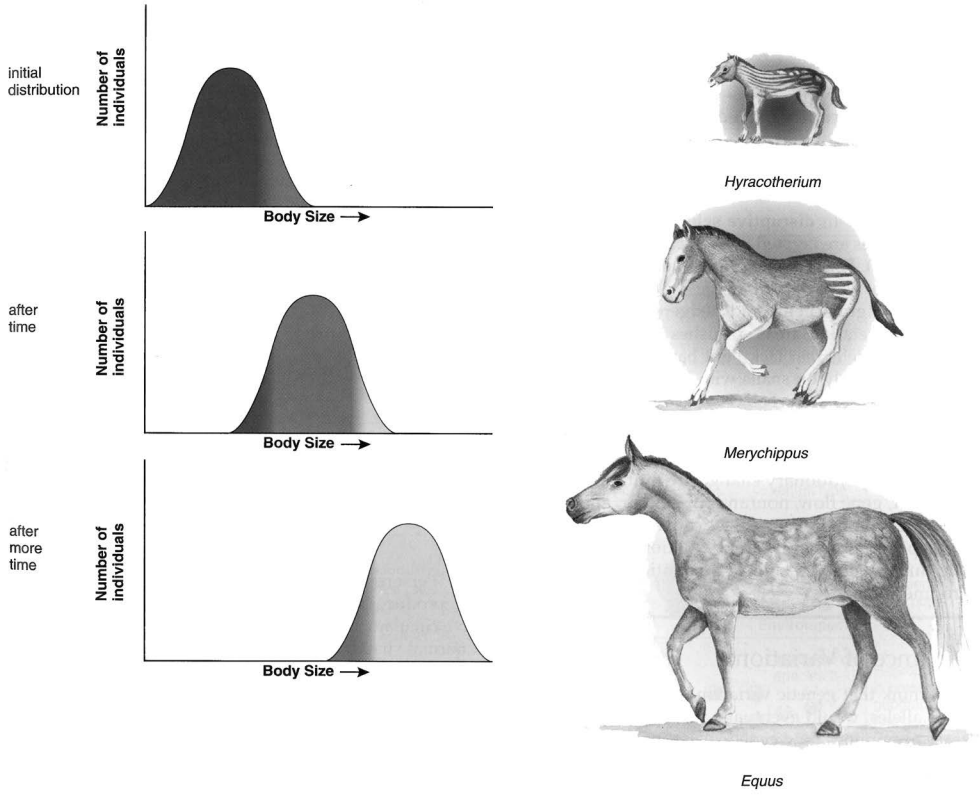
Gradualism describes the pattern of slow and gradual evolutionary change over long periods of time. Over a relatively short period of time, this type of change is hard to notice. Populations slowly diverge from one another due to differing selective pressures. The changes result in transitional forms that are seen in the fossil record.

Charles Lyell was the scientist who influenced the thinking of Charles Darwin by proposing the theory of *uniformitarianism*, the idea that processes we see now also occurred in the past. Darwin theorized that evolution must occur gradually over time.

A study of the fossil record shows that some species have their evolutionary history documented in great detail. For example, the modern horse is believed to have evolved from a fox-sized, forest-dwelling ancestor belonging to the genus *Hyracotherium*. As evolution continued, its ancestors became better adapted to live on the plains and became significantly taller. Its diet changed from foliage to grass. Speed became increasingly important on the plains so that the animals could escape predators. It also became important for their teeth to become stronger as they fed more on coarse grasses. Early ancestors of the horse walked on a number of spread-out toes. As the horse group evolved and speed became increasingly important, all the toes began to lift gradually until the animal's weight fell on one toe, which became increasingly stronger. Now that digit is seen as the horse's hoof.

Consider the illustration of some of the ancestors of the modern horse in Figure 3.15.

Figure 3.15 **Directional Selection**



Source: Mader, Sylvia S. *Inquiry into Life*. 11th ed. New York, NY: McGraw-Hill, Higher Education, 2006. 561.

The evolution of *Equus*, the modern horse's genus, did not progress in a straight line, as the above illustration possibly suggests. The evolutionary progression from *Hyracotherium* to *Equus* has been very complex and has branched many times. The modern horse represents only one branch on this evolutionary tree; in fact, it is simply the only genus of this evolutionary change to have survived until today. Some of the branches probably occurred gradually, while others probably occurred much more rapidly.

The evolution of the modern horse has been well studied and the fossil evidence for the progression is much stronger for the horse than for many other species.

Sometimes, gaps exist in the fossil record; intermediate species or forms are not documented in it. Gradualism suggests that these gaps exist because the fossils of the intermediate forms have not yet been found. These "missing links" are sometimes found when new fossils are discovered. An example of such a find was the fossil of *Archaeopteryx* in 1860 in Germany. A number of fossils of this organism have since been found and documented. *Archaeopteryx* possesses some characteristics of reptiles and some of birds. It is believed to represent an intermediate form between those two groups of organisms. The fossil indicates the organism's feathers, membranous wings, scaly legs, claws, and toothed beak. You will learn more about this organism in Lesson 3, Module 4.

Punctuated Equilibrium

Punctuated equilibrium describes the pattern of long stable periods in which species stayed much the same. These long, stable periods were interrupted (punctuated) by short periods in which the quick pace of evolution rapidly resulted in the formation of new species. The stimulus for evolution is a sudden significant change in the environment. The fossil record shows that rapid bursts of evolution have often followed mass extinctions; an example of this type of event occurred during the Cretaceous period when a rapid increase of mammalian species followed the extinction of the dinosaurs.

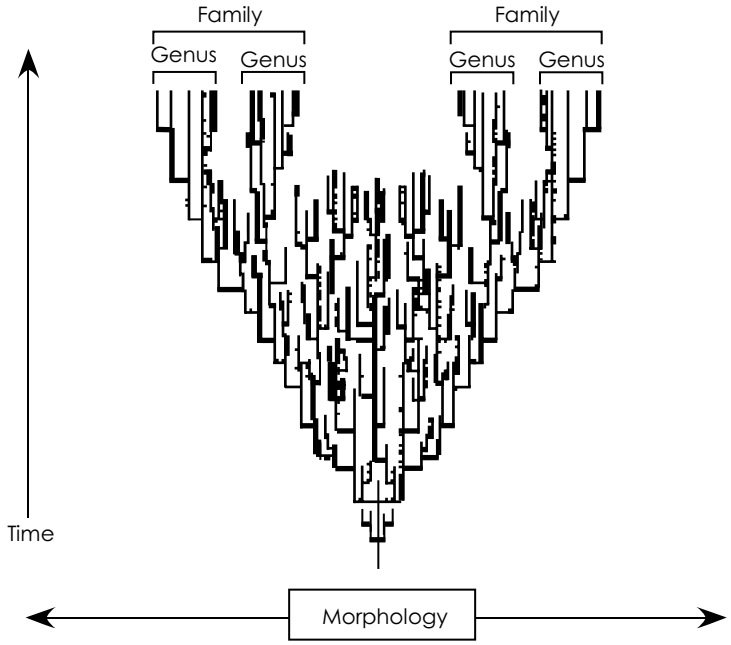
This type of evolutionary change is explained, in part, by theorizing that mutations occur in a population in order to make the organisms possessing them even more fit than organisms not possessing them. You can see how a major change in the environment might suddenly favour new traits that appear in the population due to mutation. The organisms that show those new traits presumably survive to reproduce more successfully, and the mutated gene becomes more common in the population.

Some of the steps in the evolution of the modern horse are believed to have happened very rapidly. The change from *Epihippus* to *Mesohippus* is believed to have happened abruptly, taking place in only a few million years. Reference to "only a few million years" may seem surprising to you; remember, however, that evolution occurs in geologic time, which is defined in hundreds of thousands or millions of years.

Recall that gaps sometimes exist in the fossil record where intermediate species or forms are undocumented. *Punctuated equilibrium* suggests that these gaps exist because the change has been so rapid that intermediate forms were not fossilized.

The illustration in Figure 3.17 provides one view of how punctuated equilibrium could work as a mechanism of evolutionary change. Over time (as you move up in the graph), the diversity of the life form increases in the shape of a fan. When the intermediate forms fail to continue, the two more extreme morphologies each begin to develop diversity of their own. This graph shows the evolution of two families of organisms from one ancestral group.

Figure 3.17 **Punctuated Equilibrium**

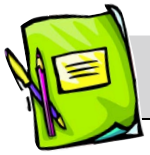


Neo-Darwinism

Our ever-changing modern synthesis of evolutionary theory is sometimes referred to as neo-Darwinism. This mass of theoretical thinking is based on evidence from genetics, population biology, paleontology, and evolutionary developmental (evo-devo) biology. Many scientists have contributed important ideas to evolutionary theory, including the following:

- **Theodosius Dobzhansky (1900–1975):** Dobzhansky was one of the biologists who initiated modern evolutionary theory that unites the fields of genetics and evolution. This line of thinking is referred to, in this module of the course, as the genetic connection. Dobzhansky is notable for defining evolution as a change in the frequency of an allele in a gene pool, and is famous for his statement that "nothing in biology makes sense except in light of evolution."

- **Ernst Mayr (1904–2005):** Like Dobzhansky, Mayr was a biologist who initiated the modern evolutionary theory that unites the fields of genetics and evolution. His work included the development of the concept of biological species and proposed one mechanism of speciation.
- **Niles Eldredge (1943 to present)** and **Stephen Jay Gould (1941–2002):** Eldredge and Gould proposed the theory of punctuated equilibrium in 1972. Recall that this theory hypothesizes that changes in species can occur relatively quickly, with long periods of little change (equilibrium) in between. Both scientists have worked on seeing how the often repeated patterns in the evolution of life forms can help refine ideas about how evolution actually occurs.



Learning Activity 3.5: Evolution and Speciation

This learning activity will give you an opportunity to review and reflect on what you have learned in this lesson about evolution and speciation.

1. Some organisms seem to have undergone very little evolutionary change over huge spans of geologic time. One example is the shark. Shark ancestry dates back around 425 million years, which is about 200 million years before the earliest known dinosaur. In all, about 2000 to 3000 species of fossil sharks have been documented. About 1100 species of shark remain on Earth today. These sharks represent an ancient life form.

   Why do you think the rate of evolution of the shark has been so gradual?

2. Some organisms seem to have undergone very rapid evolutionary change over relatively short spans of geologic time. One example is the sudden rise of mammals after the extinction of the dinosaurs. Mammals first appear in the fossil record during the Triassic period. Dinosaurs also appear in the fossil record from that time period. Early mammals were very small and had characteristics similar to those of marsupials and monotremes, such as the spiny echidna. During the Cretaceous extinction of the dinosaurs, mammals suddenly diversified into many new forms. They have since become a dominant life form on Earth.

   Why do you think the mammals evolved so rapidly?

(continued)

Learning Activity 3.5: Evolution and Speciation (continued)

3. What example in Lesson 5, Module 3, provides evidence that both gradualism and punctuated equilibrium may operate at different times during the evolution of a particular organism?

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 3.5. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this final lesson of Module 3, you have studied two main approaches to understanding the pace of evolutionary change: gradualism and punctuated equilibrium. These approaches represent a divergence from pure Darwinian thinking about evolution, which stressed slow, steady change over time. You have also studied both convergent evolution and divergent evolution, two patterns of evolutionary change that illustrate how important environmental pressures are in determining which traits are beneficial to a group of organisms. Throughout this module, you have learned that evolution is the foundation upon which modern biology is built. The pioneering work of Charles Darwin sheds light on one of the most important guiding forces in the natural world: natural selection.

Notes

Assignment 3.5: Evolution and Speciation (18 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 3.

Answer the following questions as clearly and concisely as you can in your own words.

1. Are the finches that Charles Darwin studied on the Galapagos Islands an example of divergent evolution or convergent evolution? Give two points to explain your thinking. *(4 marks—2 marks for each point)*

(continued)

Assignment 3.5: Evolution and Speciation (continued)

2. Explain how each of the following events can contribute to the reproductive isolation of a segment of a population. *(8 marks—2 marks for each event)*

   a) Geographic isolation

   b) Niche differentiation

   c) Behavioural change

   d) Physiological change

(continued)

Assignment 3.5: Evolution and Speciation (continued)

3. Explain how the concepts of gradualism and punctuated equilibrium address how organisms change over time. Give one example from Lesson 5, Module 3, of a line of organisms that is believed to have undergone **each** of these two types of evolutionary change. *(4 marks—2 marks for each approach, with example)*

(continued)

Assignment 3.5: Evolution and Speciation (continued)

4. What is one way in which Darwinian evolutionary theory is different from neo-Darwinian evolutionary theory? Explain. *(2 marks)*

Module 3 Summary

Congratulations! You have finished Module 3 of this course.

Submitting Your Assignments

It is now time for you to submit your assignments from Module 3 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 3 assignments and organize your material in the following order:

- ❑ Cover Sheet for Module 3 (found at the end of the course Introduction)
- ❑ Assignment 3.1: Science and Evolution
- ❑ Assignment 3.2: Theories of Evolutionary Change
- ❑ Assignment 3.3: Adaptation
- ❑ Assignment 3.4: Population Genetics
- ❑ Assignment 3.5: Evolution and Speciation

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

Notes

Module 3 Summary

Congratulations! You have finished Module 3 of this course.

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- ❑ Assignment 3.4: Population Genetics
- ❑ Assignment 3.5: Evolution and Speciation

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

Notes

Grade 12 Biology (40S)

Module 3
Evolutionary Theory and Biodiversity

Learning Activity Answer Key

Module 3:
Evolutionary Theory and Biodiversity

Learning Activity 3.1: Science and Evolution

This learning activity consisted of two parts.

Part A

Read each statement below and indicate whether you think it is true or false. If you think a statement is false, change it so that it becomes a true statement.

1. Science has proven that supernatural phenomena do not exist.

   False. Science cannot address supernatural phenomena since they cannot be directly observed or tested. It neither confirms nor contradicts their existence.

2. Scientific theories are clearly proven to be true if the scientific method has been applied correctly.

   False. Scientific theories are not proven to be true. Evidence gathered may either support or contradict scientific theories but does not prove their validity.

3. Scientists are certain that evolution occurs.

   True.

4. Scientists are certain about how evolution occurs.

   False. The mechanisms of how evolution occurs remain theoretical as scientists continue to try to understand the process. Evidence is constantly being generated to support a number of theories regarding the mechanisms of evolution.

5. Divergent evolution is a process that has contributed to the great biodiversity that exists on Earth.

   True.

Part B

Match the terms on the left with the correct definitions on the right.

Match	Term
C	1. genome
E	2. convergent evolution
H	3. vestigial structures
F	4. gene pool
A	5. marsupial
I	6. divergent evolution
J	7. fossil record
B	8. embryology
G	9. homologous structures
D	10. analogous structures

Definition
A. A pouched mammal; most species are found in Australia.
B. The study of the early development of a species of organism; provides evidence of evolutionary relationship.
C. All the genes possessed by a particular organism.
D. Structures that perform similar functions in organisms that are not evolutionarily related.
E. Occurs when unrelated species become structurally similar because of similar environmental pressures.
F. The total set of genes possessed by a certain population of organisms.
G. Structures that perform different functions in organisms that are evolutionarily related.
H. Structures that are present but serve no apparent purpose, providing a form of evidence for evolution.
I. Occurs when related species become structurally different because of different environmental pressures.
J. Provides many examples of how organisms have changed over time based on their physical remains.

Learning Activity 3.2: The Theory of Natural Selection

In this learning activity, you completed each of the following 15 statements, choosing the correct term (or terms) from the list provided below. Not all terms were used.

List of Terms

adapted	FitzRoy	physiological
Australia	genetics	South America
Beagle	Henslow	speciation
behavioural	Lamarck	structural
biodiversity	Lyell	Titanic
camouflage	Mendel	variation
competition	mimicry	Wallace
fittest	natural selection	Watson

1. The name of the ship on which Charles Darwin travelled to the Galapagos Islands was the ***Beagle***.
2. The scientist who suggested the theory of uniformitarianism was **Lyell**.
3. **Lamarck** proposed a theory of adaptation that included the inheritance of acquired traits.
4. The theory that Darwin proposed to explain the mechanism driving evolutionary change is the theory of **natural selection**.

5 The friend and mentor of Charles Darwin who encouraged him to travel to the Galapagos was **Henslow**.

6. The Galapagos Islands are located off the coast of the continent of **South America**.
7. Darwin was amazed by the incredible amount of **biodiversity** that he found on the Galapagos Islands.
8. The captain of the ship on which Darwin travelled to the Galapagos was **FitzRoy**.
9. Three types of adaptations that exist are **behavioural**, **physiological**, and **structural**.

(continued)

Learning Activity 3.2: The Theory of Natural Selection (continued)

10. Two types of structural adaptations are **mimicry** and **camouflage**.
11. One of the important ideas in Darwin's theory is that more offspring are produced in each generation than can survive; this results in **competition** between members of the same species.
12. Individuals within the population that possess beneficial traits are said to be well **adapted** to the environment.
13. Survival of the **fittest** means that organisms that are well adapted will tend to survive and reproduce more successfully than other organisms.
14. **Speciation** is the development of new species from ancestral species as natural selection continues over time.
15. The man who put forth a theory very similar to Darwin's theory of natural selection was **Wallace**.

Learning Activity 3.3: Adaptation

In this learning activity, you defined each of the following terms:

1. adaptation

   A phenotypic characteristic of an organism that allows it to survive to reproduce more successfully than an organism that does not possess it.

2. artificial selection

   A human action in which the parents of a cross are chosen based on phenotypic characteristics that are desired in their offspring.

3. directional selection

   Selective pressure that favours individuals possessing values for a trait at one extreme of the distribution, and selects against the average and the opposite extreme.

4. disruptive selection

   Selective pressure that favours individuals at both ends of the distribution and selects against the average. It is also known as diversifying selection.

5. evolution

   The change that occurs in living things over time.

6. gene pool

   The complete set of genes in a particular population of organisms that affect a particular trait.

7. genetic variation

   The natural variation in genotype and phenotype that exists in a population of organisms.

8. industrial melanism

   Refers to the appearance of dark coloration in the peppered moth in Manchester, England; a pale-coloured moth was more common in the area before industrialization and a dark-coloured variant was more common in the area after industrialization.

9. natural selection

   The mechanism of evolutionary change that was first proposed by Charles Darwin; according to this theory, environmental pressures choose the individuals that are best adapted to survive and reproduce.

10. stabilizing selection

    Selection that favours individuals with an average value for a trait, and selects against those with extreme values.

Learning Activity 3.4: Population Bottlenecks and Endangered Species

For this learning activity, you read information about the whooping crane population and used the information to answer the following four questions.

Questions

1. Whooping cranes are an example of an endangered species that has passed through a population bottleneck. Explain how a population bottleneck can alter the genetic variation in the gene pool of a species.

   Because the population reaches such a low number of individuals in a population bottleneck, only a few individuals contribute genes to the entire future population of the species. Much genetic variation within the species is lost, and allelic frequencies change significantly in the remaining gene pool.

2. How does a population bottleneck affect the ability of a species, such as the whooping crane, to evolve and adapt to environmental changes?

   The lack of genetic variation reduces the ability of the whooping cranes to adapt to environmental changes. There is little variation upon which natural selection can act.

3. How could the population bottleneck affect the ability of the whooping cranes to recover from near extinction?

   No matter how many whooping cranes there are, the species will always be at risk of extinction. Their genetic homogeneity makes them potentially more sensitive to disease and genetic conditions associated with inbreeding.

4. Why should people try to protect and conserve an endangered species?

   Answers may vary. They may include points such as the following:

   - Humans caused the whooping crane population to decline by hunting them and destroying their habitat.
   - Our actions caused the whooping crane's gene pool to become a gene "puddle."
   - The human population has become so large and is consuming so many resources that we are forcing our neighbours out of their homes.
   - We should practise good stewardship and preserve our world for future generations.

Learning Activity 3.5: Evolution and Speciation

In this learning activity, you reviewed and reflected on what you had learned about evolution and speciation.

1. Some organisms seem to have undergone very little evolutionary change over huge spans of geologic time. One example is the shark. Shark ancestry dates back around 425 million years, which is about 200 million years before the earliest known dinosaur. In all, about 2000 to 3000 species of fossil sharks have been documented. About 1100 species of shark remain on Earth today. These sharks represent an ancient life form.

   Why do you think the rate of evolution of the shark has been so gradual?

   One line of thinking suggests that the ocean environment of the shark has not changed significantly over time; since environmental pressures have remained fairly constant, stabilizing selection has kept allele frequencies relatively constant. Since environmental pressures have remained fairly constant, new mutations usually do not provide an adaptive advantage and, therefore, disappear over time.

2. Some organisms seem to have undergone very rapid evolutionary change over relatively short spans of geologic time. One example is the sudden rise of mammals after the extinction of the dinosaurs. Mammals first appear in the fossil record during the Triassic period. Dinosaurs also appear in the fossil record from that time period. Early mammals were very small and had characteristics similar to those of marsupials and monotremes, such as the spiny echidna. During the Cretaceous extinction of the dinosaurs, mammals suddenly diversified into many new forms. They have since become a dominant life form on Earth.

   Why do you think the mammals evolved so rapidly?

   One line of thinking is that rapidly changing environmental conditions caused a mass extinction of the dinosaurs. This opened up a great diversity of ecological niches. As a result, the genetic variation that already existed in mammals allowed different forms to fill different niches successfully. Over time, those different forms diverged from one another. Speciation occurred relatively rapidly as a result.

3. What example in Lesson 5, Module 3, provides evidence that both gradualism and punctuated equilibrium may operate at different times during the evolution of a particular organism?

   The example provided in Lesson 5 was the evolution of the modern genus of horses, *Equus*.

Notes

Biology Videos

Module 3

1. Video - What is Evolution?
2. Video - Evolution: It's a Thing - Crash Course Biology #20
3. Video - Evidence for evolution | Biology | Khan Academy
4. The Making of a Theory: Darwin, Wallace, and Natural Selection
5. Video - DARWIN'S THEORIES
6. Video - Charles Darwin - The Theory Of Natural Selection
7. Video - What is SURVIVAL OF THE FITTEST? What does SURVIVAL OF THE FITTEST mean?
8. Video - Adaptation and Natural Selection
9. Video - Natural Selection
10. Video - Population Genetics: When Darwin Met Mendel - Crash Course Biology #18
11. Video - Population Genetics
12. Video - Genetic Drift
13. Video - Speciation
14. Video - Evolution and Speciation
15. Video - Speciation

Grade 12 Biology (40S)

Module 4
Organizing Biodiversity

Module 4:
Organizing Biodiversity

Introduction

Is a bird more closely related to a lizard than to a dragonfly? Are mushrooms correctly called plants? Are bacteria really living organisms?

Early in Module 3 of this course, you learned about how evolution has led, over time, to the incredible biodiversity that exists on Earth. You studied the genetic connection to help you understand how change occurs, over time, in populations of organisms. You learned about natural selection, the mechanism of evolutionary change suggested by Charles Darwin. And you saw how selective pressures in the environment can cause genetic change in populations of organisms in nature.

In Module 4, you will study the biodiversity present on Earth. You will also learn about human efforts to organize living things into groups, an effort that shows us how organisms are related and increases our understanding of the natural world. Classification schemes used in biology have changed and continue to change as scientific knowledge grows.

Scientists have identified about two million species of living things on Earth. It has been estimated that the actual number of species on Earth may be as high as between five million and 30 million species. In an effort to understand this incredible diversity of life, scientists study evolutionary connections and try to classify organisms into meaningful groups.

So, is a bird more closely related to a lizard than to a dragonfly? You can find out by studying the biodiversity of life on Earth.

Module 4 Assignments

When you have completed the assignments for Module 4, submit your completed assignments to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 4.1	Biodiversity
2	Assignment 4.2	North American Bear Species
3	Assignment 4.3	Systems of Classification
4	Assignment 4.4	The Three Domains of Life
5	Assignment 4.5	Evolutionary Trends

Lesson 1: Defining Biodiversity

Lesson Focus

In this lesson, you will

- ❑ define the concept of biodiversity in terms of ecosystem, species, and genetic diversity

Introduction

The need to organize, classify, and name is basic to human nature. By organizing things into groups, naming those groups, and then comparing the groups, we gain a better understanding of the things we are studying. Classifying things into groups is a useful process.

Attempting to understand the life forms on Earth is a daunting task of dealing with two million or more known types of life forms. How can we hope to understand such an incredible number? One approach lies in comparing and categorizing living things.

What Is Biodiversity?

Biodiversity can be defined as the range of life in an area that is determined and sometimes quantified as the number of different species in that area. The size of an area can vary, depending on the scope of the study.

In Module 3, you learned that, over time, the process of evolutionary change has led to the biodiversity that exists now. In this lesson, you will learn about three types of biodiversity: species diversity, genetic diversity, and ecosystem diversity.

Species Diversity

Species diversity refers to the number of species found in an ecosystem. Some ecosystems on Earth, such as a tropical rain forest, have a high level of species diversity. Tropical rain forests are found in the latitudes near the equator. Long growing seasons and abundant rainfall have led to the successful evolution of a great diversity of living things. Other ecosystems, such as the tundra environment that exists near the North Pole and near the South Pole, have a low level of species diversity. Fewer species live in the tundra environment because of its extreme temperatures and harsh conditions. In fact, biological diversity drops in either direction from the equator to the poles. While the latitudinal pattern is particularly well understood, biodiversity varies with longitude and altitude as well.

More than half the known species on Earth are insects. About 75 percent of all animals are insects. Since there are virtually no insect species in the oceans, the species diversity is generally far lower in marine environments than in terrestrial environments. The best-described groups of organisms are the birds and mammals, even though the number of known species belonging to these two groups is relatively small compared to that of other groups. The least-described groups of organisms are believed to be the insects, worms, fungi, and microbes. The areas in the world that are least understood in their complexity are deep-sea areas and tropical rainforests.

Some areas on Earth possess particularly high levels of biological diversity. These areas are sometimes referred to as biodiversity hot spots. Examples of such areas are coral reefs, the Amazonian rainforest, and the tropical island of Madagascar off the coast of Africa.

Genetic Diversity

Genetic diversity refers to the variety of genes or the traits that are expressed in a particular population of organisms. Many phenotypic characteristics that you studied in the previous modules of this course are clear indicators of genetic diversity. Examples of such characteristics include colour, resistance to disease, body size, and cell structure.

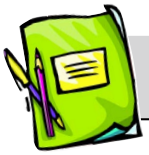
In general, the greater the genetic diversity that exists in a population of organisms, the greater the chances are that this population will survive a change in its environment. Environmental change is inevitable; when a population possesses enough genetic diversity, some of its members are able to survive the change and reproduce. If the genetic diversity present in a population is low due to inbreeding or genetic isolation, environmental change may wipe out the population entirely.

Ecosystem Diversity

Ecosystem diversity refers to the incredible variety of ecosystems that exists on Earth. An ecosystem is made up of both the living organisms in an area and the physical environment; it is composed, therefore, of both biotic and abiotic factors. The characteristics of an ecosystem depend on many variables, such as physical geography, climate, latitude, longitude, and altitude.

Some ecosystems, such as tropical rainforests, are found all around the world; however, not all these ecosystems are identical. The biological populations supported in rainforests in Indonesia are not exactly the same as those found in South American rainforests, for example, and the organisms that exist in the Rocky Mountains of North America are not exactly the same as those found in the Himalayan Mountains of Asia.

All the combined ecosystems on Earth are considered to be one unit called the *biosphere*. The Earth's biosphere is a huge, complex, and ever-changing entity whose lifeblood is water. Water supports all the beautiful life forms that exist on Earth.



Learning Activity 4.1: Biodiversity

In this learning activity, you will explain some of the concepts discussed in this lesson.

1. Define *biodiversity*.
2. Name and briefly explain the three aspects of biodiversity that you have learned about in this lesson.
3. Why do humans study, compare, categorize, and name living things?
4. What process has led to the great diversity of species on Earth?

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 4.1. The assignment details can be found after the Lesson Summary.

Lesson Summary

In Lesson 1, you have learned about the concept of biodiversity. You have learned that there are three types of biodiversity: species diversity, genetic diversity, and ecosystem diversity. In the next lesson, you will learn about the biological concept of species. Composing a concise, accurate, and widely applicable definition of *species* has posed quite a problem for biologists for many years. As their understanding of genetics and evolution has continued to increase, scientists have periodically had to question the usefulness of definitions of species in biology.

Assignment 4.1: Biodiversity (9 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 4.

1. Explain how ecosystem diversity is related to species diversity in terms of evolutionary change. *(3 marks)*

(continued)

Assignment 4.1: Biodiversity (continued)

2. Refer to your answer to question 1. Illustrate your answer by naming **two** related species that have evolved differently because their environments differ. For each species, describe the ecosystem in which it is found. Explain how their respective environmental differences led to differences between the related species. *(6 marks—3 marks for each species)*

Lesson 2: Defining a Species

Lesson Focus

In this lesson, you will

- ❑ explain why it is difficult to determine a definition of *species*

  Examples: hybrids such as mules, phenotypic variations in a species, non-interbreeding subpopulations . . .

Introduction

Is it possible for a female dog to mate successfully with a male wolf? Do dogs and wolves belong to the same species? Do horses, donkeys, and mules belong to the same species? What about horses and zebras?

Questions such as these arise when biologists consider how to define a biological species adequately. A dependable definition of species must be determined before organisms can be classified into groups. Physical similarities and differences are important, but so are similarities and differences in behaviour, ecology, and distribution. You will begin this lesson by looking at how biologists currently define a species.

What Is a Species?

The earliest definition of *species* stated that all the individuals in a species resemble a particular and distinct type of organism. This typological species idea depended largely on physical characteristics such as size and colour.

In Module 3, you learned about Charles Darwin's voyage to the Galapagos Islands in the mid-nineteenth century. While on those islands, Darwin studied a variety of finches that varied significantly from one another. Each group of finches had its own physical characteristics, ecological niche, behaviour, diet, and habitat. When the different groups of finches were found to interbreed, the offspring were sterile. Likewise, a cross between a horse and a donkey results in sterile offspring: a mule. These examples illustrate that a *species* can be defined as a group of related organisms that can successfully interbreed to produce **fertile** offspring.

There are difficulties, however, with that definition. Ernst Mayr, an evolutionary biologist, defined a *biological species* as a reproductive community of populations (reproductively isolated from others) that occupies a specific niche in nature. This definition implies that members of a species are genetically similar to one another. Members of the same species share common DNA sequences. Furthermore, members of different species cannot interbreed to produce fertile offspring because the DNA possessed by the two parents is too dissimilar.

Remember that individuals belonging to the same species may not closely resemble one another in terms of appearance or behaviour; however, they do closely resemble one another in terms of genetics. Consider, for example, the domesticated dog. All dogs belong to the same species, *Canis familiaris*. Theoretically, all dogs can interbreed to produce fertile offspring. Even chihuahuas and Great Danes belong to the same species. Another example of phenotypic variation within a species occurs in the white-tailed deer, *Odocoileus virginianis*. Male deer possess noticeable antlers for much of the year; females do not possess antlers at all. Furthermore, during mating season, male deer display aggressive behaviours not seen in female deer.

Since scientific knowledge regarding the inheritance of traits and genetics has increased so much in the last half century, the *biological species* concept has been modified to include a reference to ancestry and evolutionary pathways. The *phylogenetic species* concept defines a species as a distinct group of organisms that share a common ancestry. Scientists now know that species are biologically distinct from one another because they possess different combinations of genetic information; in addition, scientists know that species possess different combinations of genetic information because they have followed different evolutionary paths. The more closely related two species are, the more similar their genetic information is—which is a reflection of their differing evolutionary pasts.

This definition of *species*, which is based on evolutionary relationship, ancestry, and distribution, is a useful one. If the members of an ancestral group become separated into two distinct and separated groups, they could, over time, become separate species. The members belonging to each group share a common line of descent and have evolved in a particular environment. This approach to defining a species takes into account shared DNA sequences. Organisms with shared ancestry also share common DNA sequences; therefore, the species is still a distinct biological unit.

It is apparent, then, that members of the same species share a great deal of genetic information in the form of DNA. When two organisms possess significantly different DNA sequences, sexual reproduction between them does not result in fertile offspring even if the physical act of mating has occurred. As a result, those two organisms would be placed in different species.

What Is a Subspecies?

Complicating this relatively clear definition of species is the fact that sometimes non-interbreeding populations can exist within a species; these organisms are placed into different subspecies as a result. You will now learn about three examples of subspecies: deer mice, domestic dogs, and domestic cats.

Deer Mice

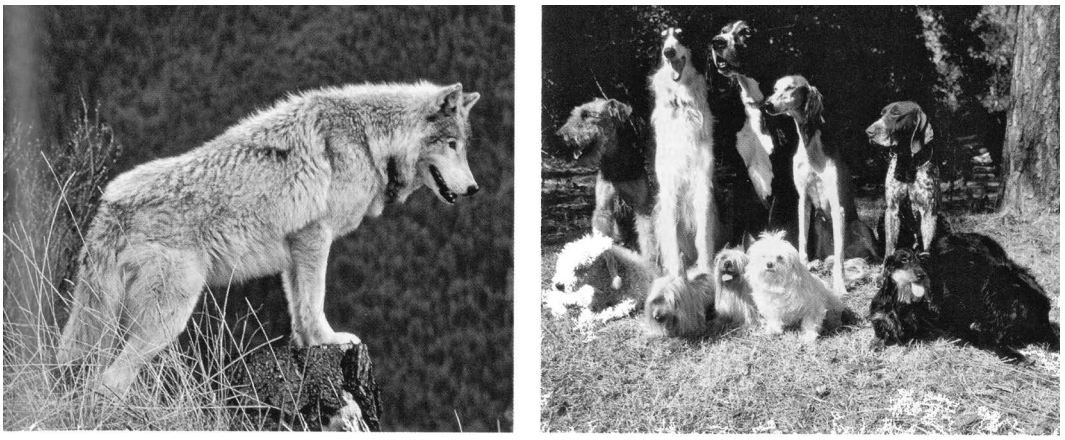
Several subspecies of deer mice, *Peromyscus maniculatus*, are present in North America. Deer mice are known as potential carriers of hantavirus. One subspecies, *P. maniculatus bairdii*, prefers open areas such as plowed or cultivated fields and grasslands. Another subspecies, *P. maniculatus gracilis*, is found in forests. In addition to occupying different habitats, the mice differ in appearance. While the two subspecies may occupy the same area, they do not interbreed. They will, however, interbreed with other subspecies of deer mice.

Dogs

The domestic dog has the scientific name, *Canis lupus familiaris*, the gray wolf has the scientific name, *Canis lupus lupus*, and the Australian dingo has the scientific name, *Canis lupus dingo*. These three animals belong to the same species but to different subspecies. They all evolved from the same ancestral stock. All breeds of dogs belong to the same subspecies.

Consider the pictures shown in Figure 4.1. The picture on the left shows the gray wolf, *Canis lupus*, and the picture on the right shows various breeds of the domestic dog. Notice the morphological similarities and differences among these animals.

Figure 4.1 **Gray Wolf and Domestic Dogs**



a) b)

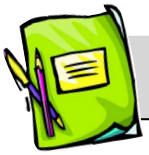
Photo credits: (a) Stephen J. Krasemann/DRK Photo (b) Timothy O'Keefe/Tom Stack & Associates

Source: Audesirk, Teresa, Gerald Audesirk, and Bruce E. Byers. *Biology: Life on Earth.* 6th ed. Upper Saddle River, NJ: Prentice-Hall, Inc., 2002. 281.

Cats

The house cat has the scientific name, *Felis silvestris catus*. The African wildcat has the scientific name, *Felis silvestris lybica*. There are two other subspecies of this species, *Felis silvestris silvestris*, the European wildcat, and *Felis silvestris ornata*, the Asiatic wildcat.

Many other examples of subspecies have been identified in nature. Sometimes, fossil evidence may lead to the conclusion that a living species should be given a subspecies name that is distinct from the scientific name given to the identified ancestor. That ancestral subspecies would normally differ morphologically in some way from the living subspecies, and that difference would be significant enough to warrant the use of a subspecies name.



Learning Activity 4.2: Case Study

For this learning activity, you will read the following case study and answer questions based on the case study. Please note that the case study includes references to scientific literature that supports the information provided. These references appear in parentheses within the text and are cited in full at the end of the case study.

As the Worm Turns: Speciation and the Apple Maggot Fly*

by Martin G. Kelly

Introduction

Hawthorn trees grow throughout North America and produce a small fruit, which is eaten by a small fly larva. In 1864, apple growers in New York State discovered that an unknown maggot had started feeding on apples. Since that time, hawthorn and apple maggot flies have become progressively more distinct from each other.

Facts about Hawthorn and Apple Maggot Flies

The apple maggot fly and the hawthorn maggot fly are both assigned to the same species, *Rhagoletis pomonella*. It is not possible to distinguish individuals of these two types of flies from one another. These two types of flies are also not geographically isolated from one another, and there is no physical separation between populations of these flies. This species is native to eastern North America and was originally bred in the fruit of hawthorn trees.

Facts about Hawthorn and Apple Trees

Both hawthorn and apple trees are woody plants that belong to the rose family. Hawthorns are a group of about 50 species of trees and shrubs that are native to North America. They belong to the genus *Crataegus*. Early Europeans introduced apples to North America. Apple trees belong to the genus *Malus*. Today, the apple is the most widely grown fruit in North America. The maggot fly is the major fruit pest in eastern Canada and northeastern United States. Effective maggot fly control efforts are needed to produce high quality fruit.

(continued)

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* Source: Kelly, Martin G. "As the Worm Turns: Speciation and the Apple Maggot Fly." 3 Dec. 2002. *Case Collection.* http://sciencecases.lib.buffalo.edu/cs/collection/detail.asp?case_id=328&id=328.

Facts about Maggot Fly Reproduction

Maggot flies that reproduce on apples are known as the apple race, while maggot flies that reproduce on hawthorns are known as the haw race. The apple race peaks from the end of July to the beginning of August and overlaps with apple fruiting from August to the beginning of September. The haw race overlaps with both the apple race and the apple fruiting in August, peaks right after the apple fruiting peak in mid-September, and overlaps with hawthorn fruiting in September and October. Hawthorn fruiting peaks during mid-October (Bush).

Adult flies emerge to reproduce before the fruits are mature. The female fly lays fertilized eggs into the ripe fruit. Maggots hatch from the eggs, eat fruit, grow, and pupate. Apple fruit ripens approximately one month earlier than hawthorn fruit. There is overlap at the end of the apple fruiting season and the beginning of the hawthorn fruiting season (Feder and Filchak, cited in Berlocher and Feder).

Facts about Hawthorn and Apple Fruit

Apples are bigger fruits than hawthorns. The typical commercial apple has a diameter of 70 mm, while the typical wild hawthorn has a diameter of 12.6 mm. The larger fruits of apple trees provide 5.5 times more depth (based on diameter) to developing maggots than do hawthorn fruits. Parasitoid wasps lay eggs into the maggot's body, ultimately killing the maggot. Apple maggots are better able to escape parasitoid wasps by burrowing deeper into the fruit than the wasp can penetrate with its ovipositor (egg-laying structure). Apple maggots bear 70 percent fewer parasitoid wasp eggs than do hawthorn maggots (Feder, cited in Berlocher and Feder).

The larger fruits of apple trees provide 220 times more food (based on volume) to the growing and developing maggot than do the smaller fruits of the hawthorn. Apple maggot flies lay more eggs per fruit than do hawthorn maggot flies. The nutritional quality of hawthorn fruit is indicated by the better survival rate of both types of maggots in hawthorn fruit; 52 percent of maggot fly eggs survived in hawthorn fruit and 27 percent of maggot fly eggs survived in apple fruit (Prokopy et al., cited in Freeman and Herron 329). Caterpillars and weevils may also feed on the larger apple, reducing the quantity of food available to apple maggots.

(continued)

Learning Activity 4.2: Case Study (continued)

Evolutionary Outcomes in Apple Maggot Flies

Fidelity to fruit type acts as a strong barrier to gene flow between the two types of maggot flies. There is only a 4 to 6 percent hybridization rate between hawthorn maggot flies and apple maggot flies (Feder et al., cited in Berlocher and Feder). Hawthorn maggot flies strongly prefer to mate on and lay fertilized eggs into hawthorn fruit. Apple maggot flies strongly prefer to mate on and lay fertilized eggs into apple fruit. Hawthorn and apple maggot flies are genetically distinguishable. They have recognizable and different genetic profiles.

References

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Reissig, W. H. Insect Identification Sheet No. 7: Apple Maggot, *Rhagoletis pomonella* (Walsh). Cornell University and the New York State IPM Program, 1991.

Seelig, R. A., and D. Hirsh. *Fruit and Vegetable Facts and Pointers: Apples.* Washington, DC: United States Fresh Fruit and Vegetable Association, March 1978.

Questions

1. State two reasons why it could be argued that hawthorn maggot flies and apple maggot flies belong to the same species.

2. State two reasons why it could be argued that hawthorn maggot flies and apple maggot flies belong to two different species.

3. Which conclusion, that hawthorn maggot flies and apple maggot flies belong to the same species or that they belong to two different species, is more strongly supported by the evidence that you have learned in this case study? Support your choice.

4. What further information would you need or would you like to have to increase your confidence in the conclusion that you reached in the previous question?

(continued)

Learning Activity 4.2: Case Study (continued)

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 4.2. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about how the word *species* has been defined and used in the science of biology. Historically, the use of the term has depended on our understanding of inheritance and evolution. In the next lesson, you will learn that schemes for classifying living things into groups have continued to change over the years as our understanding of genetics and evolutionary change has itself evolved.

Assignment 4.2: North American Bear Species (22 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 4.

Part A

Consider the case of the North American brown bear, *Ursus arctos*. Do some research to find information about this species of bear. Then answer the following questions.

1. What is the brown bear's range in North America at the present time? *(3 marks)*

2. Does physical variation exist in this species, especially in terms of fur colour and size? Explain. *(3 marks)*

(continued)

Assignment 4.2: North American Bear Species (continued)

3. Are any identified subspecies of the North American brown bear found only in North America? If so, what are they and where are they found? *(3 marks)*

4. The North American brown bear belongs to the species *Ursus arctos*, while the polar bear belongs to the species *Ursus maritimus*. What differences between the brown bear and the polar bear provide evidence that these two types of bears belong to separate species? Remember that this evidence could exist in the form of physical differences, ecological differences, or differences in patterns of their geographic distribution. *(3 marks)*

(continued)

Assignment 4.2: North American Bear Species (continued)

Part B

One subspecies of the brown bear is the grizzly bear, *Ursus arctos horribilis*. It has long been suspected that grizzly bears and polar bears may interbreed in the wild in some areas where their ranges overlap. As you learned in Lesson 5, Module 3, a white bear with brown patches was found dead in the Northwest Territories in 2006. DNA tests later confirmed that the bear was the offspring of a male grizzly bear and a female polar bear. It was the first grizzly-polar hybrid bear found in the wild. The hybrid animal has been named a *pizzly* or a *grolar bear*.

5. Do pizzlies, grizzlies, and polar bears actually belong to the same species? What evidence do you have for your answer? Explain your reasoning as clearly as possible. If you assume pizzlies are fertile, how would this affect your answer. *(4 marks)*

(continued)

Assignment 4.2: North American Bear Species (continued)

Part C

Carolus Linnaeus (1707–1778) introduced a system of classifying organisms, which you may have learned about in previous science courses. (This system will also be discussed in the next lesson.) With the Linnaean classification system, each species is given a scientific name in two parts, the first word in the name indicating the organism's genus and the second word indicating its species. The genus name is capitalized and the species name is not. Both names are derived from Latin words that describe the organism being named. Both words are italicized.

The Linnaean name (binomial name) for the North American brown bear is *Ursus arctos*.

6. Identify two other bears (not already discussed) by both their Linnaean (genus and species) and familiar (common) names. Include a few facts about each genus, such as its habitat, diet, and behaviour.
   (6 marks—3 marks for each genus)

Lesson 3: Systems of Classification

Lesson Focus

In this lesson, you will

- ❑ describe the dynamic nature of classification

  Include: different systems and current debates

- ❑ describe types of evidence used to classify organisms and determine evolutionary relationships

  Examples: fossil record, DNA analysis, biochemistry, embryology, morphology . . .

Introduction

In the first two lessons of this module, you learned about two major concepts, biodiversity and biological species. In this lesson, you will continue to learn about these two concepts. In addition, you will learn about how the concepts of biodiversity and the definition of a species are interwoven within scientific understanding of evolutionary change. Scientists classify organisms into groups because it helps them to understand those organisms and the environments in which they live, as well as how organisms have changed over time.

Systematics

Earlier in this module, you learned that classifying living things into groups and then naming those groups helps us to understand living things. When we place them into groups, we try to identify what the members of any one group have in common. We also look for commonalities and differences between the identified groups. These commonalities and differences are especially useful in the search for evolutionary patterns. The more closely related two types of living things are, the more recent their common ancestor is believed to be.

Branches within Systematics

Systematics is the branch of biology that deals with classifying living things, both those that are alive now and those that are now extinct. There are three aspects to the science of systematics:

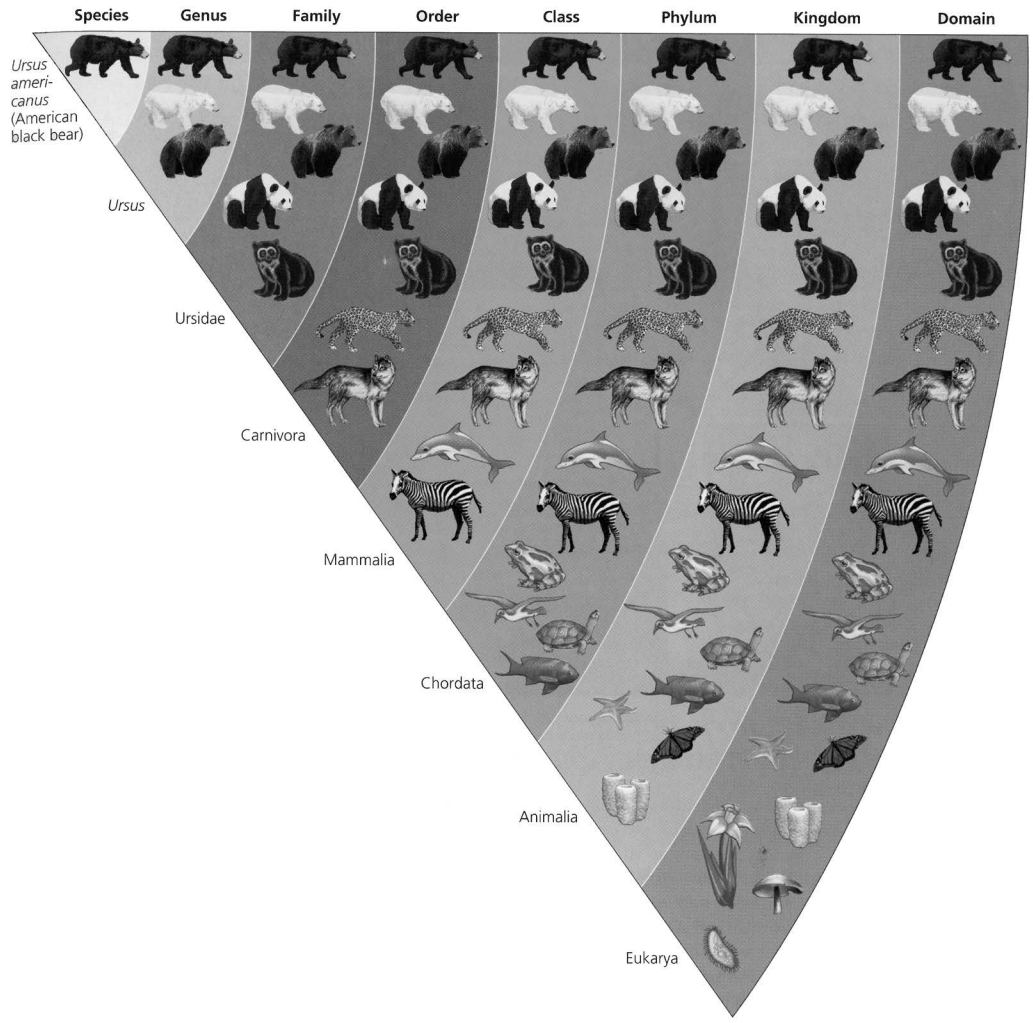
- **Taxonomy:** the study of describing and naming biological groups.
- **Classification:** organizing information about organisms by arranging them into a hierarchical system.
- **Phylogenetics:** determining the evolutionary history and relationships among the various forms of life through time. Relationships among organisms are expressed through diagrams known as *cladograms*.

A Brief Review of the Taxonomic Hierarchy

The groups that are used in taxonomy are hierarchical in nature. In Figure 4.2, which uses the species *Ursus amaricanus* (American black bear) as an example, groups are classified from the smallest to the largest group: species, genus, family, order, class, phylum, kingdom, and domain.

Within each level of taxonomy, the terms *sub*, *super*, and *infra* are sometimes used. For example, a group of related orders within a particular class may be referred to as a *subclass* or a *superorder*. Of these taxonomic levels, the only one that has any ecological significance in nature is the species level, since it is defined on the basis of not only morphology, but also reproduction.

Figure 4.2 **Classifying Life**



Source: Campbell, Neil A., and Jane B. Reece. *Biology*. 7th ed. San Francisco, CA: Pearson Education, Benjamin Cummings, 2005. 13.

A Brief History of Classification

Systems for classifying living things into groups have changed dramatically over the years. You will now learn about some scientists who have contributed to our understanding of classification and about discoveries that have influenced classification systems dramatically. These advances are discussed in roughly chronological order.

- **Aristotle (384–322 BCE):** Aristotle created the first widely used system of classification by dividing all living things into two groups: plants and animals.

- **Carolus Linnaeus (1707–1778):** Linnaeus developed the hierarchical system of classifying organisms based on their resemblance to other organisms, a modified form of which is still in use today. From largest to smallest, his categories of classification are: kingdom, phylum, class, order, family, genus, and species. He also introduced the system of naming called *binomial nomenclature* that is still used today. With this system, each species is given a scientific name in two parts. The first word in the name indicates the organism's genus and the second word in the name indicates its species. Both words are italicized. The genus name is capitalized and the species name is not. Both names are derived from Latin words that describe the organism being named. For example, the scientific name for human is *Homo sapiens*, a Latin term that means thinking human.
- **Ernst Haeckel (1834–1919):** In 1866, Haeckel suggested that the organisms recently discovered through the invention of the microscope be placed in a new kingdom, which he called *Protista*. Improvements in light microscopes led to a rapidly expanding body of knowledge concerning microscopic life.
- **Electron microscopes:** The invention of the electron microscope and advances in biochemistry in the mid-1900s led to the discovery of two distinctly different types of cells on Earth: the prokaryotes (bacteria) and the eukaryotes (plants, animals, fungi, and protists).
- **Robert Whittaker (1920–1980):** In 1959, Whittaker proposed the *five-kingdom system* of classifying organisms. Plants, animals, fungi, bacteria, and protists were placed in separate kingdoms: Plantae, Animalia, Fungi, Monera, and Protista.
- **Carl Woese (1928–):** In the 1970s, Woese analyzed the base sequence of ribosomal RNA in various bacteria, which led him to suggest that bacteria be subdivided into two distinct groups: the Eubacteria and Archaebacteria.
  - **Six-kingdom system:** Based on Woese's research, a six-kingdom system of classifying life was suggested. The plant, animal, fungi, and protist kingdoms remained, while the bacteria kingdom was separated into the Eubacteria and Archaebacteria kingdoms.
  - **Three-domain system:** In 1990, Woese proposed the three-domain system of classification consisting of the following domains:
    - Eukarya (all eukaryotes, including animals, plants, fungi, and protists)
    - Bacteria ("true" bacteria such as *Escherichia coli*, *Lactobacillus bulgaris*, and *Cyanobacteria*)
    - Archaea (organisms that live in extreme environments, such as high temperature or extreme salinity, or produce methane gas)

In Figure 4.3, showing the three domains of life, notice that the Eukarya domain is the largest domain, containing all protists, plants, fungi, and animals.

Figure 4.3 ***Life's Three Domains***

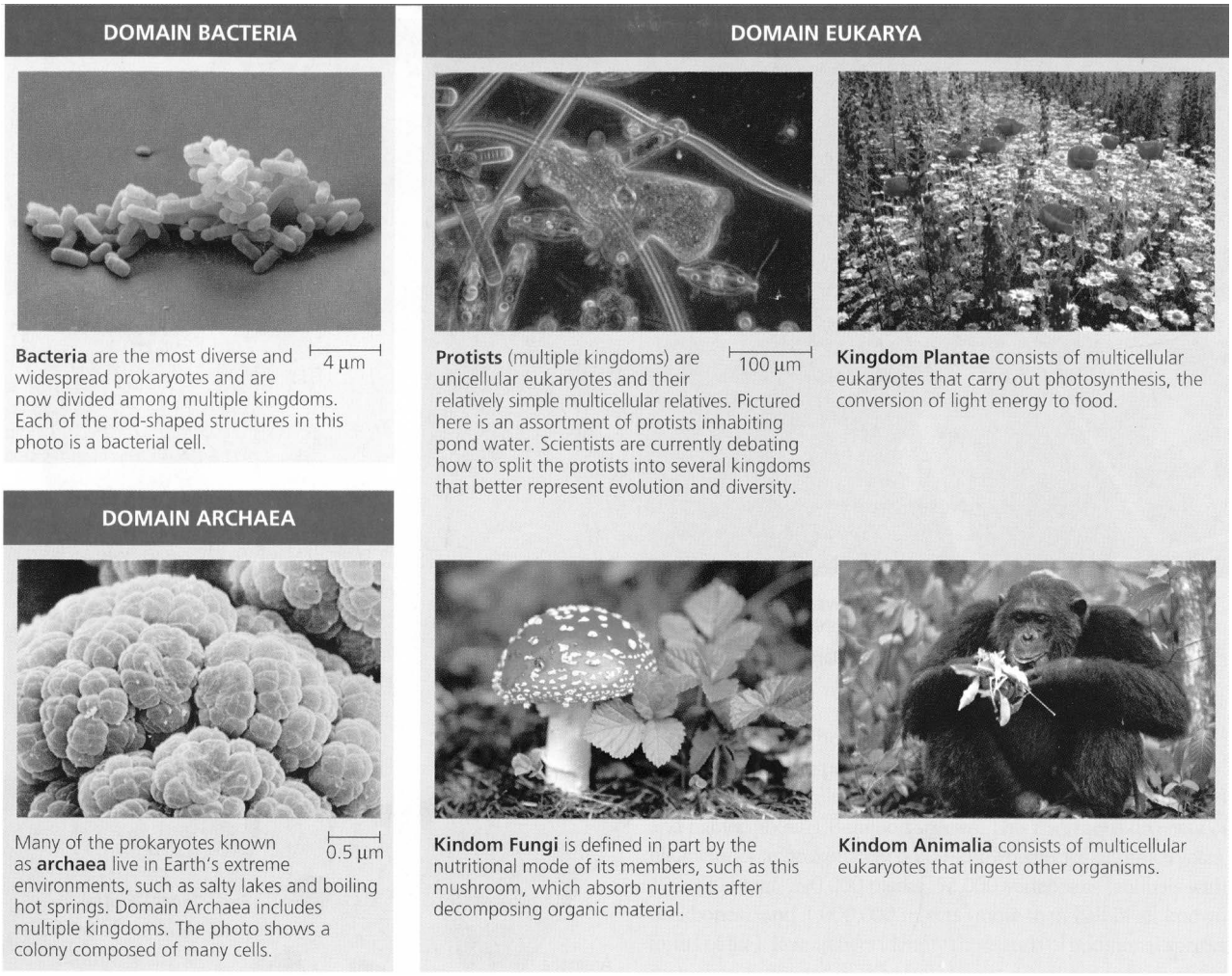


Photo credits: Oliver Meckes/Nicole Ottawa/Photo Researchers (top left), Ralph Robinson/Visuals Unlimited (bottom left), D. P. Wilson/Photo Researchers (top middle), Konrad Wothe/Minden Pictures (top right), Peter Lilja/Taxi (bottom middle), Anup Shah/Nature Picture Library (bottom right)

Source: Campbell, Neil A., and Jane B. Reece. *Biology*. 7th ed. San Francisco, CA: Pearson Education, Benjamin Cummings, 2005. 14.

Since 1990, knowledge of biochemistry has continued to expand. As a result, systems of classification continue to change. Even the most recent textbooks may quickly be out of date, as classification schemes are constantly adjusted to reflect growing scientific knowledge. DNA and RNA sequencing is very useful to biologists as they try to determine how organisms are related through evolution. As scientific knowledge grows, groupings continue to be modified.

Approaches to Classification

The two primary approaches to the classification of living things are the phenetic method and the cladistic method, which are discussed below:

- **Phenetic method:** With this traditional classification method, organisms are classified according to similarities and relationships in morphology (physical forms and structures). This method does not reconstruct evolutionary relationships among organisms. It can be difficult to use this method because of the great phenotypic variation that can exist within a species and because different scientists may value various morphological features differently. For example, is a sparrow more closely related to a penguin than to a bat? The sparrow and the penguin both have feathers, but the sparrow and the bat both have wings used for flight.
- **Cladistic method:** Introduced by German biologist Willi Hennig, *cladistics* (*phylogenetic systematics*) uses phylogenetics as the determining factor in classification. It emphasizes descent and common ancestry to determine the evolutionary history of groups of organisms. *Cladograms* are diagrams that show evolutionary relationships based on shared inherited features, and do not rank organisms into phyla, class, order, and so on. Organisms are organized in *clades*, groups of organisms that include an ancestor and all descendants of that ancestor.

These two methods may result in the same classification scheme, but often do not, as shown in the example that follows.

Example: Vertebrate Evolution and Classification

Vertebrate classification has followed two different lines of thinking: the phenetic approach and the cladistic approach:

- **Phenetic approach:** As this approach depends heavily on morphology as the basis of classification, it was thought that the classification of vertebrate animals within the kingdom Animalia should follow this pattern:

  Phylum: Chordata
  Subphylum: Vertebrata
  Class: Agnatha (jawless fishes)
  Chondrichthyes (cartilaginous fishes)
  Osteichthyes (bony fishes)
  Amphibia (amphibians)
  Reptilia (reptiles)
  Aves (birds)
  Mammalia (mammals)

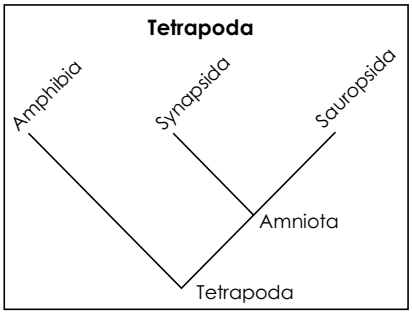
  Terrestrial vertebrates live on land. Traditional phenetic classification separates these vertebrate animals into four classes: amphibians, reptiles, birds, and mammals. Three major classes of fish are recognized:

  - Agnatha (jawless fishes, such as lampreys)
  - Chondrichthyes (cartilaginous fishes, such as sharks and rays)
  - Osteichthyes (bony fishes, such as salmon and guppies)

  According to this system of classification, mammals appear to be no more related to reptiles than they are to amphibians. Birds appear to be no more related to reptiles than they are to mammals.

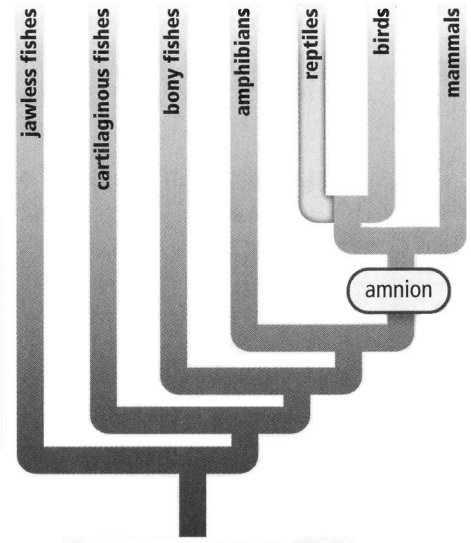
- **Cladistic approach:** Cladistics places all terrestrial vertebrates into the group Tetrapoda, which contains two groups: Amphibia and Amniota. Amphibians are animals such as frogs, salamanders, and toads. Amniotes are animals such as turtles, snakes, crocodiles, dinosaurs, birds, and mammals. Amniota consist of two major groups: the Synapsida (which are mammals) and the Sauropsida (which are reptiles and birds). A cladogram of the Tetrapoda and its subgroups is shown in Figure 4.4.

Figure 4.4 **Cladogram of the Tetrapoda**



This line of thinking puts greater emphasis on the reproductive strategies of animals than on morphology. The cladogram in Figure 4.5 shows that it is believed that mammals and reptiles share a much more recent common ancestor than the common ancestor shared by reptiles and amphibians. Furthermore, it places modern reptiles in the same taxonomic group as birds, Sauropsida. This reasoning is supported by the discovery of fossils such as *Archaeopteryx*, which will be discussed later in this lesson.

Figure 4.5 **Phylogenetic Tree**



Source: Biggs, Alton, et al. *Glencoe Science Biology*. Columbus, OH: Glencoe/McGraw-Hill, 2009. 852.

The cladogram shown in Figure 4.5 illustrates an ever-increasing understanding of evolutionary relationships. Based on fossil evidence, biochemical analyses, genetic studies, and morphological comparisons, scientists now believe that reptiles and birds share a very recent common ancestor. Reptiles and birds share a less recent common ancestor with mammals. All three of those groups—reptiles, birds, and mammals—share an even less recent common ancestor with amphibians. The taxonomic grouping Tetrapoda is separate from the fish. In the phenetic approach, the three classes of fish were no more related to one another than they were to the other four classes of vertebrate animals—amphibians, reptiles, birds, and mammals. Clearly, the cladistic approach to classification helps scientists to group organisms based on how they are related in terms of evolution.

This example shows that the phenetic and cladistic approaches may result in different schemes of classification. The organisms are the same organisms; that is, classifying them does not change them. Systems of classification change when we focus on different characteristics to use as criteria.

Evidence Used to Classify Organisms

How do biologists decide on which characteristics are the important ones when they classify and name organisms? Is it more important to look at the physical features of an organism or at its geographical distribution? Is it more important to look at behavioural patterns or at ecological niches? How important are genetic similarities? What about other biochemical similarities?

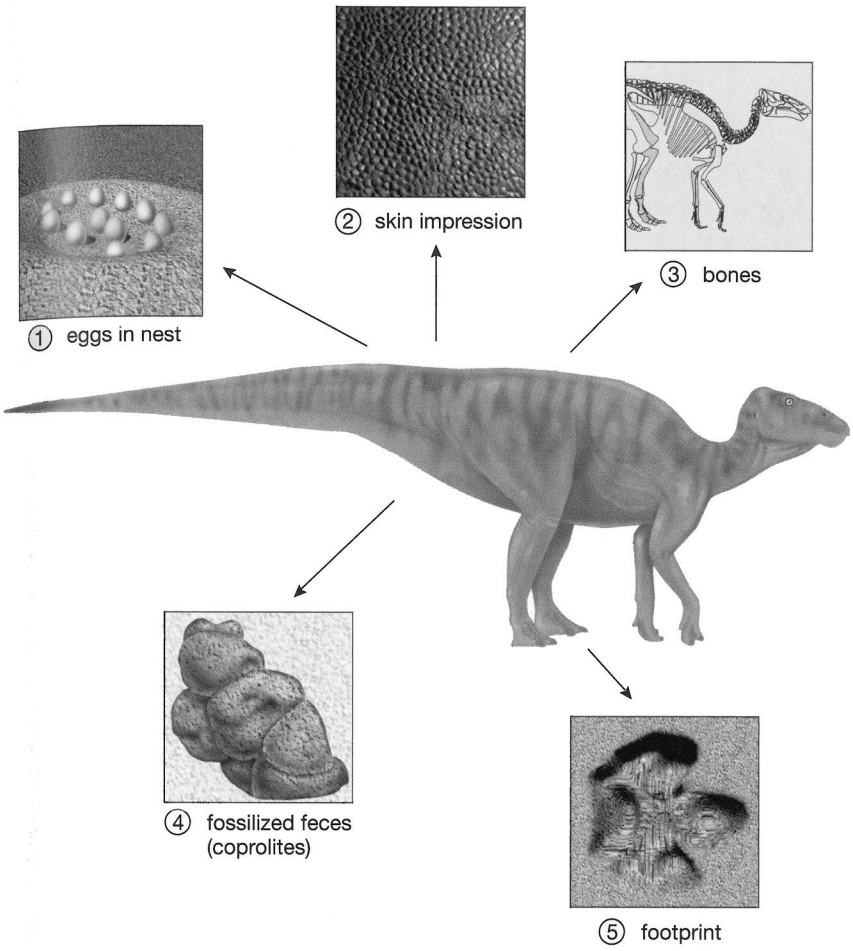
Biologists use various types of information or evidence to classify and name organisms, including fossil evidence, DNA evidence, biochemistry, embryology, and morphology. A discussion of these types of evidence follows.

Fossil Evidence

Paleontology, the study of fossils, is a useful tool in classification. A *fossil* is a piece of physical evidence of an organism. When we think of fossil evidence, we may first think of casts and moulds that were formed when sediment gradually filled in physical impressions of life forms. But there are other types of fossil evidence as well. In some cases, footprints were left, and then preserved when the substrate solidified. Crystals can replace the organic material that an organism is made of, producing a mineralized fossil. Organisms sometimes become trapped in sticky amber, which may harden and preserve the organic material within it. Over time, organic material may also become frozen or mummified. Scientists can study that material to gain a better understanding of the organism from which it came long ago.

Consider the graphic in Figure 4.6. It illustrates various types of fossil evidence that could be found of the organism shown.

Figure 4.6 **Types of Fossils**



Source: Audesirk, Teresa, Gerald Audesirk, and Bruce E. Byers. *Biology: Life on Earth*. 6th ed. Upper Saddle River, NJ: Prentice-Hall, Inc., 2002. 271.

Fossils are dated in a variety of ways. Sometimes, scientists know the approximate age of the rock layer in which a particular fossil is found. In other cases, radiometric dating methods that make use of radioactive elements are used to date fossils. It is important to recognize that fossils must be dated before any conclusions can be drawn from them.

By studying fossil evidence, scientists try to build an understanding of how life has evolved on Earth. The fossil record is always growing and is far from complete. Scientists believe that about 99 percent of the organisms that ever lived on Earth are now extinct. Only a very small fraction of the organisms have been preserved as fossils, and only a small fraction of the fossils that

exist have been found and studied by humans. Still, the fossil record that exists is very useful in helping us to understand evolution and to classify organisms into meaningful groups.

An example of how fossil evidence can help in classifying organisms is provided by *Archaeopteryx*, a fossil first found in 1860 in Germany, and named in 1861 by paleontologist Hermann von Meyer. *Archaeopteryx*, illustrated in Figure 4.7, is believed to have lived about 150 million years ago. It had a reptilian tail, scales, and teeth. At the same time, it also had wings and a body covered with feathers. Examination of fossil evidence indicates that its brain was very similar to the brains of modern birds. This fossil evidence suggests to paleontologists that birds evolved from reptilian dinosaurs. Scientists now believe that birds share a common ancestor with present-day reptiles such as crocodiles.

In China, the Liaoning Province is an area that is particularly rich in fossil evidence. For many years, scientists have been making important discoveries in that location. Fossil specimens belonging to the genus *Caudipteryx* possess feathers and strong legs; these animals probably used their feathers more for insulation and stability than for flight. Individuals belonging to another genus, *Confuciusornis*, probably lived in trees instead of on the ground; they also possessed feathers.

Figure 4.7 **Archaeopteryx and Caudipteryx**

Source: Biggs, Alton, et al. *Glencoe Science Biology*. Columbus, OH: Glencoe/McGraw-Hill, 2009. 868.

Birds and reptiles that are alive today share many morphological features. For example, their skeletons are very similar, the functioning of their livers and kidneys are very similar, and both groups lay eggs on land. Fossil evidence helps us to understand how reptiles have evolved, how birds have evolved, and how dinosaurs figured into that evolutionary picture.

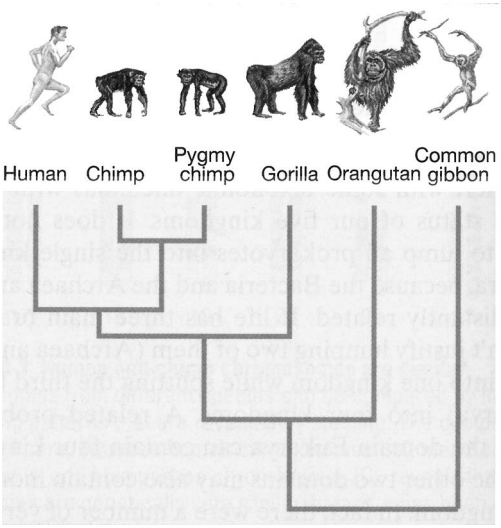
The fossil record is important in both phenetic and cladistic approaches to classification.

DNA Evidence

By comparing the DNA of different organisms, scientists can better understand how they are related. Recall that DNA and RNA are the genetic molecules found in all life forms on Earth. Nucleic acids control how a cell looks and how it acts; they determine phenotypes of many different types. As a result, organisms that share traits (phenotypes) also share DNA sequences. That genetic evidence helps scientists to understand how organisms are related and how they should be classified.

It is now possible for scientists to compare the entire genomes of organisms. By comparing the genomes of organisms, similarities and differences in sequencing can be identified. For example, when making DNA comparisons between a squirrel monkey, a chimpanzee, and a gorilla, scientists find that the DNA sequences of the chimpanzee and the gorilla are much more similar than either is to the genome of the squirrel monkey. All three animals are primates. This indicates that the common ancestor shared between the chimpanzee and the gorilla is more recent than the common ancestor shared between those two animals and the squirrel monkey. This distinction is reflected in the classification of these animals. The graphic in Figure 4.8 shows the degree of relatedness between humans and five other primates.

Figure 4.8 **Relatedness between Humans and Other Primates**

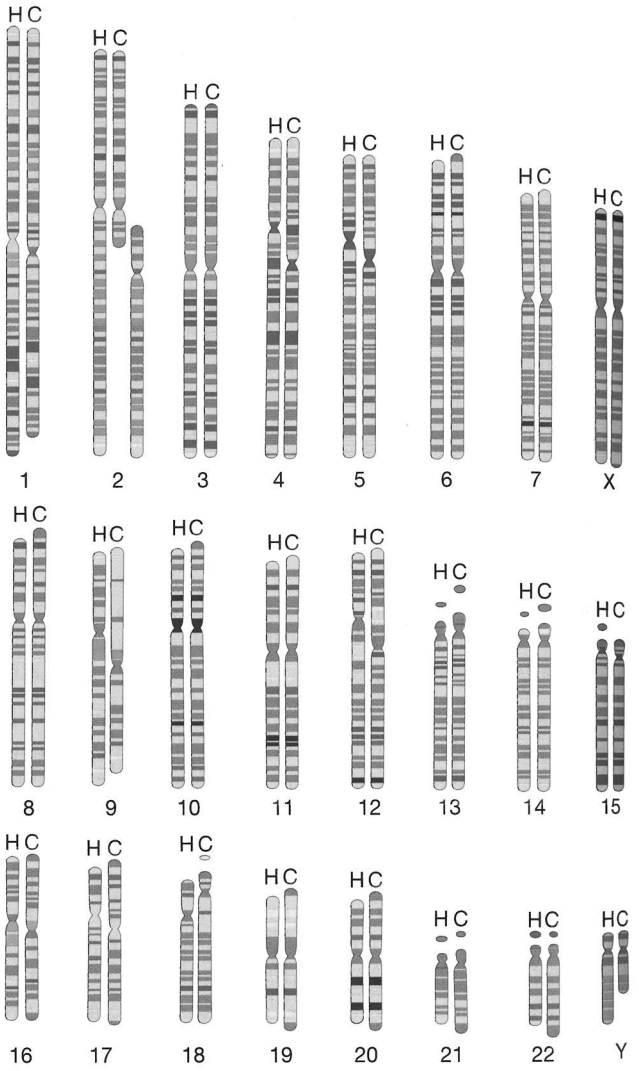


Source: Audesirk, Teresa, Gerald Audesirk, and Bruce E. Byers. *Biology: Life on Earth*. 6th ed. Upper Saddle River, NJ: Prentice-Hall, Inc., 2002. 356.

Monkeys, apes, and tarsiers all belong to the order Primates. Within that order, there are many families. The family to which the squirrel monkey belongs is Cebidae, the New World monkeys. The chimpanzee and gorilla belong to a different family, Hominidae; humans belong to this family as well. Organisms that belong to the same order are related, but organisms that belong to the same family are even more related. The family Hominidae contains within it a number of genera. The genus in which the gorilla is placed is *Gorilla*. The genus to which the chimpanzee belongs is *Pan*. And the genus to which humans belong is *Homo*.

The graphic in Figure 4.9 shows the similarities that exist between human and chimpanzee genetic information. It is estimated that about 99 percent of the two genetic codes are identical.

Figure 4.9 **Similarities between Human and Chimpanzee Chromosomes**



Source: Audesirk, Teresa, Gerald Audesirk, and Bruce E. Byers. *Biology: Life on Earth.* 6th ed. Upper Saddle River, NJ: Prentice-Hall, Inc., 2002. 354.

The study of DNA sequences is especially useful in the cladistic approach to classification.

Biochemistry

Nucleic acids of different organisms are not the only chemicals that can be compared to learn about evolutionary histories of organisms. Another group of organic compounds that can be studied are proteins. Amino acids are the building blocks of protein molecules. By comparing amino acids, both in terms of which amino acids are present and in terms of the particular sequences in which they are found, scientists can better understand how different organisms are related to one another. This understanding of relatedness helps us to classify organisms in more meaningful groups.

Recall from previous lessons in this course that amino acid sequences are determined by nucleotide sequences. So, similarity in the DNA of two organisms is expressed as *protein similarity*.

Biochemical analysis is especially useful in the cladistic approach to classification.

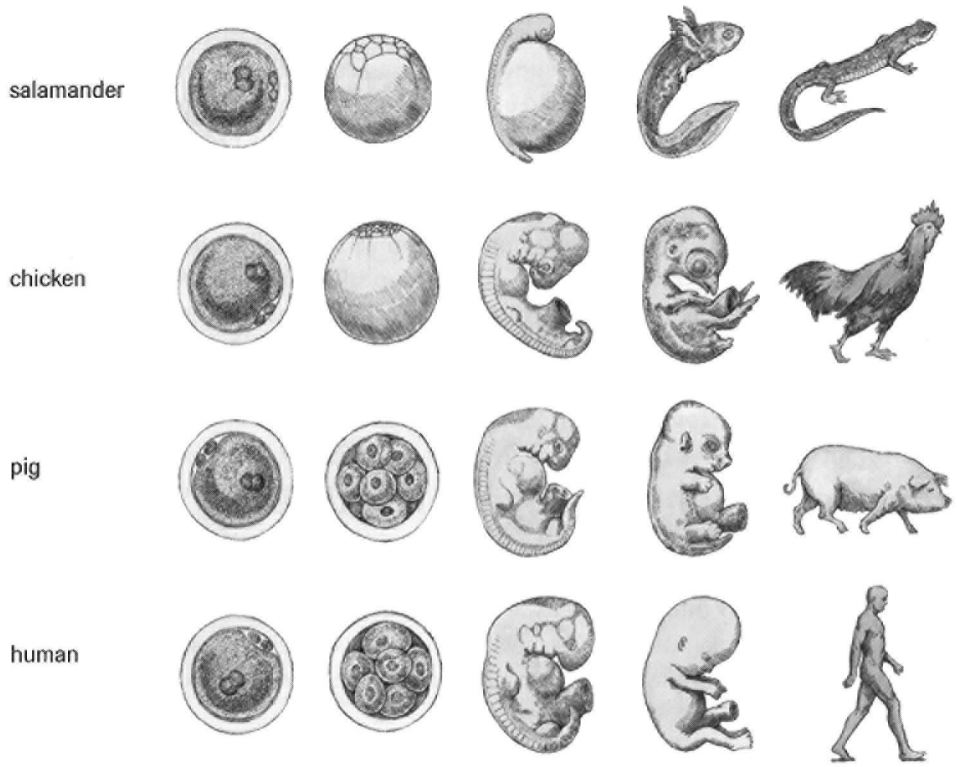
Embryology

An *embryo* is a very young form of a developing organism. Identifying embryological similarities and differences can help scientists to understand how closely related different vertebrate animals are; this understanding helps them to classify the animals.

The embryos of vertebrate animals share a number of embryonic similarities. For example, they all possess a tail that disappears to varying degrees as the embryos continue to develop. All vertebrate embryos also possess a pair of "gill slits"; these structures develop into gills in fish, and into the ears, jaws, and throats of reptiles, birds, and mammals. These embryological similarities show how recently the common ancestor of these organisms existed. The more recent the common ancestor is, the more closely related the two organisms are.

Figure 4.10 shows similar features that appear in the embryos of various animals—an amphibian, a bird, and two mammals.

Figure 4.10 **Embryos of Various Animals**



Source: Di Giuseppe, Maurice, et al. *Nelson Biology 12*. Toronto, ON: Nelson, a division of Thomson Canada Limited, 2003. 524.

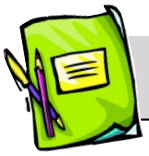
Embryology is especially important in the phenetic approach to classification, since it emphasizes morphology.

Morphology

Morphology deals with the study of an organism's physical characteristics. By looking at various morphological features, scientists can get a better idea of the evolutionary relationship between the organisms possessing them. When a trait evolves once and is shared by two existing species, those species are said to be related and share a common ancestor that displayed that trait. Scientists can get an idea of how recently a trait evolved by looking at the fossil record.

For example, it is believed that vertebrate animals that live on land, such as reptiles, birds, and mammals, share a common ancestor. It is also believed that vertebrates with paired limbs evolved from ancient vertebrates that had paired fins. So, reptiles, birds, and mammals are more closely related to one another than they are to fish. Amphibians share a common ancestor with the three groups of terrestrial vertebrate animals that is more recent than the common ancestor amphibians share with finned fish.

Another connection supported by biochemical and genetic evidence is the connection between birds, reptiles, and dinosaurs. Scientists now believe that birds and dinosaurs share a common ancestor that is more recent than the common ancestor shared by dinosaurs, birds, and present-day reptiles. In other words, birds are more closely related to dinosaurs, all of which are extinct, than they are to present-day reptiles. The most recent common ancestor that birds share with present-day reptiles is the one they share with crocodiles.



Learning Activity 4.3: Systems of Classification

This learning activity will give you an opportunity to review what you have learned about systems of classifying living organisms.

1. Briefly explain the contributions that the following individuals made to classifying and naming living organisms:
   a) Aristotle
   b) Carolus Linnaeus
   c) Ernst Haeckel
   d) Robert Whittaker
   e) Carl Woese
2. Compare and contrast the two approaches used to classify organisms: phenetics and cladistics. How are they similar and how are they different? Explain.
3. Name and briefly explain three forms of evidence that biologists use to classify and name organisms.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 4.3. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned more about how biologists organize and use classification systems to help them understand living organisms. It is important to realize that the schemes of classification used in biology continue to change with increasing knowledge about organisms. Research continues to shed light on scientific understanding of evolution, genetics, biochemistry, and morphology. As our knowledge about the natural world increases through research, we become aware of new questions to ask and new pathways of research to investigate. We will never totally understand the natural world. Our efforts to understand it have led to the classification schemes that we use at any point in time.

In the next lesson, you will learn about the classification scheme that is currently used, that of the three domains: Bacteria, Archaea, and Eukarya.

Assignment 4.3: Systems of Classification (12 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 4.

Answer the following questions.

1. How can studying the fossil remains of organisms from the distant past assist in classifying life forms that live on Earth at the present time? *(3 marks)*

(continued)

Assignment 4.3: Systems of Classification (continued)

2. Define the two major approaches used to classify organisms: phenetics and cladistics. Describe one strength and one weakness of **each** approach. *(6 marks)*

(continued)

Assignment 4.3: Systems of Classification (continued)

3. What information do *Archaeopteryx* fossils provide that helps biologists to classify modern birds? *(3 marks)*

Notes

Lesson 4: The Three Domains of Life

Lesson Focus

In this lesson, you will

- ❑ compare the characteristics of the domains of life

  Include: Archaea (Archaebacteria), Bacteria (Eubacteria), and Eukarya

- ❑ compare the characteristics of the kingdoms in the Eukarya domain

  Include: cell structure, major mode of nutrition, cell number, and motility

Introduction

In this lesson, you will learn about the classification scheme currently used by biologists. Instead of using kingdoms, biologists use domains as the largest taxonomic groups. Three domains have been identified: Bacteria, Archaea, and Eukarya. All living things can be placed into one of these domains, depending on a number of evolutionary, biochemical, genetic, and morphological characteristics.

The Three Domains

When biologists attempt to classify life forms on Earth, they must consider the simplest organisms first. The simplest organisms are often the most ancient organisms. As biologists search for evidence about ancient life forms, they discover that little fossil evidence exists of primitive, single-celled organisms. For this reason, they look at present-day single-celled organisms to gain a better understanding of the evolution of all life forms that exist today.

You will now learn about the three domains biologists currently use to classify life forms on Earth and about the characteristics that distinguish one from another.

Domain Bacteria

Members of the Bacteria domain are composed of prokaryotic cells. Scientists now believe that all life forms on Earth have evolved from ancient prokaryotic cells. Prokaryotic cells do not possess nuclei; they possess genetic material, but it is not contained within a nucleus. The genetic material in this type of cell is small and circular in shape. The prokaryotic cells that still exist on Earth today are believed to belong to two large taxonomic groups: Bacteria and Archaea.

The Bacteria domain contains the "true" bacteria. The only kingdom within this domain is Eubacteria. The Bacteria domain is believed to be less closely related to the other two domains than they are to each other. In other words, the common ancestor that Eubacteria share with Archaebacteria and eukaryotic cells is more ancient than the common ancestor shared by those other two domains.

Eubacteria do not possess membrane-bounded nuclei or membrane-bounded organelles. Their cell walls are composed of a polymer called peptidoglycan. True bacteria live in a variety of environments, and are the most numerous life forms on Earth. Some bacteria are aerobic and, therefore, require oxygen to survive, while others are anaerobic and can survive without oxygen. Some are autotrophic and manufacture their own food, while others are heterotrophic and lack that ability (a heterotroph gets its nutrients and energy from consuming other organisms). It is believed that both aerobic respiration (which uses oxygen to release chemical energy from food molecules) and photosynthesis (which uses carbon dioxide and produces oxygen) evolved in organisms belonging to the Eubacteria.

Domain Archaea

Members of the Arachaea domain are also composed of prokaryotic cells. Today, the organisms belonging to this domain live in extreme environments that probably resemble those of ancient Earth in which they evolved.

The only kingdom within this domain is Archaebacteria. It is believed that present-day Archaebacteria evolved from a primitive prokaryotic life form that also gave rise to organisms in the other two domains.

The Archaebacteria gave rise to the following three primary types of organisms:

- **extreme halophiles:** cells found only in extremely saline environments (most cells would die in such environments)
- **extreme thermophiles:** cells found in very hot aquatic environments such as vents in the ocean floor and hot springs on land
- **methanogens:** cells that produce methane as a metabolic by-product

Archaebacteria are prokaryotic and, therefore, lack membrane-bounded nuclei and organelles. Their cell walls do not contain peptidoglycan. Some forms are aerobic and others are anaerobic. Archaebacteria may be either autotrophic or heterotrophic.

Domain Eukarya

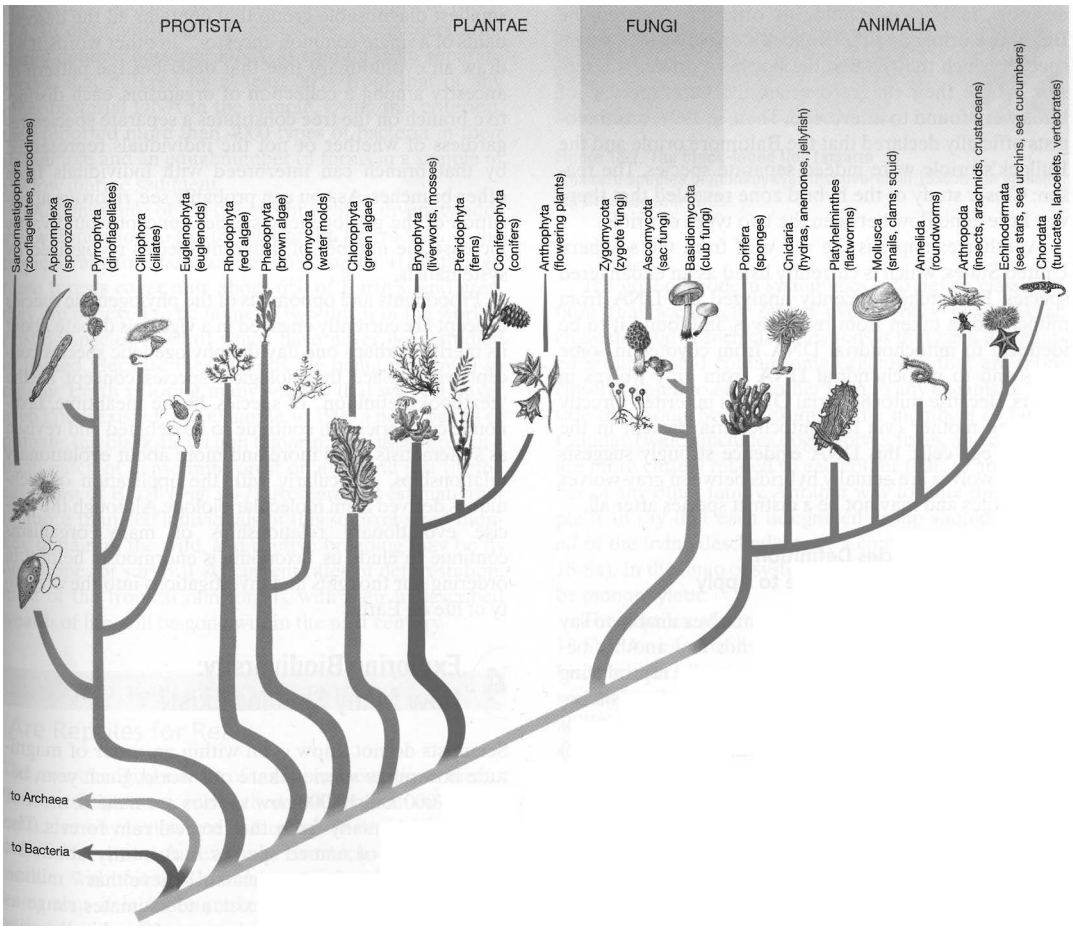
Members of the Eukarya domain are composed of eukaryotic cells. Eukaryotic cells, unlike prokaryotic cells, possess true nuclei. The genetic material in these cells is contained within a nuclear membrane and is, therefore, separated from the cytoplasm. Genetic material in eukaryotic cells is found in the form of chromosomes. As you have already learned, the common ancestor that eukaryotic cells shared with Archaebacteria existed more recently than the common ancestor that eukaryotic cells shared with Eubacteria. It is currently believed that the first eukaryotic cells appeared about two billion years ago on Earth.

In addition to possessing true nuclei, eukaryotic cells also possess membrane-bounded organelles that are suspended within the cytoplasm. The organelles that possess membranes in eukaryotic cells include vacuoles, endoplasmic reticulum, mitochondria, and chloroplasts. Some eukaryotic cells are photosynthetic and others are heterotrophic.

All organisms on Earth that possess eukaryotic cells belong in the domain Eukarya. Early in their evolutionary past, eukaryotic cells existed as individual, unicellular organisms. As evolution continued, multicellular life forms began to increase in number. Sexual reproduction evolved, which allowed for much greater genetic recombination than was allowed by asexual forms of reproduction alone. Early examples of more complex life forms, such as plants, fungi, and animals, began to evolve roughly 750 million years ago.

Members of the Eukarya domain are placed into a number of kingdoms: Protista, Fungi, Plantae, and Animalia. The graphic in Figure 4.11 is one illustration of the kingdoms and organisms belonging to the Eukarya domain. A discussion of the five kingdoms that belong to the Eukarya domain follows.

Figure 4.11 **Eukarya Domain**



Source: Audesirk, Teresa, Gerald Audesirk, and Bruce E. Byers. *Biology: Life on Earth*. 6th ed. Upper Saddle River, NJ: Prentice-Hall, Inc., 2002. 357.

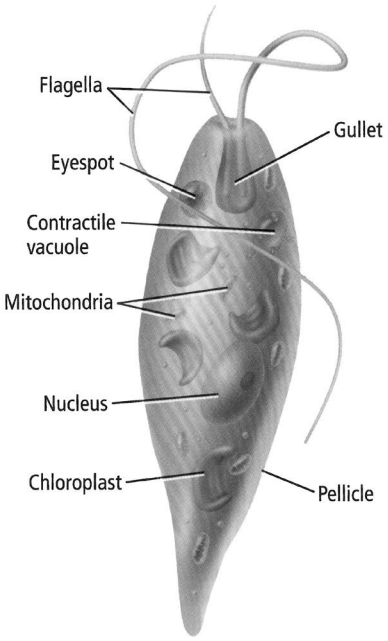
Kingdom Protista

The Protista kingdom contains the most primitive forms of eukaryotic cells on Earth today. Protists may be unicellular, colonial, or multicellular. This kingdom consists of a wide variety of organisms. Some bear very little resemblance to one another—except that they do not fit into any other kingdom of eukaryotes.

Protists are classified into three large groupings:

- **Plant-like protists:** These protists are the algae; they are photosynthetic and resemble plants in their general appearance when they are multicellular. Sea kelp is an example of a plant-like protist. The euglena is an example of a photosynthetic, unicellular protist that is capable of movement; because it is an autotroph, it is usually classified as a plant-like protist. The *Euglena gracilis* illustrated in Figure 4.12 has characteristics of both plants and animals.

Figure 4.12 ***Euglena gracilis***



Source: Biggs, Alton, et al. *Glencoe Science Biology*. Columbus, OH: Glencoe/McGraw-Hill, 2009. 556.

- **Animal-like protists:** These protists are the protozoa. They are not photosynthetic; instead, protozoa eat their food and are, therefore, heterotrophic. The amoeba and paramecium are examples of protozoa. Figure 4.13 shows an amoeba extending its pseudopods.

Figure 4.13 ***Amoeba***

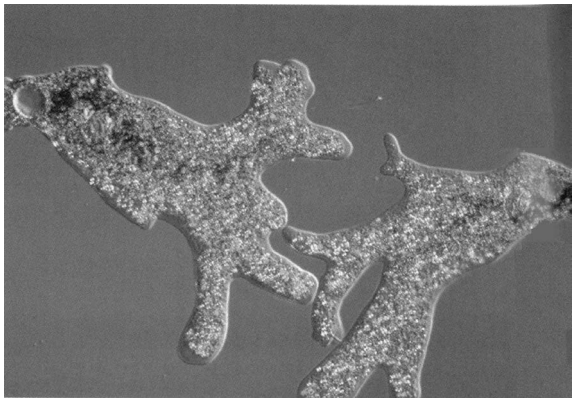


Photo credit: M. I. Walker/Photo Researchers, Inc.

Source: Audesirk, Teresa, Gerald Audesirk, and Bruce E. Byers. *Biology: Life on Earth*. 6th ed. Upper Saddle River, NJ: Prentice-Hall, Inc., 2002. 384.

- **Fungus-like protists:** The slime moulds and mildews belong to this group of protists. Although their life form is more primitive than that of true fungi, the slime moulds and mildews possess many similar characteristics. For example, both groups usually absorb nutrients from dead organic material.

Kingdom Fungi

Organisms belonging to this kingdom are either unicellular or multicellular. They are heterotrophic and do not move. Like plants, they possess cell walls. Unlike plant cells, however, fungal cells possess chitin in their cell walls. Chitin is a very rigid substance that provides support to fungal cells. A fungus generally consists of a mass of thin, fibrous filaments that are called hyphae. These hyphae anchor the fungus to the substrate on which it is living; they also allow the fungus to reproduce, feed, and grow.

Common examples of organisms in this kingdom are mushrooms. There are actually about 70,000 species of fungi known to exist on Earth today. The organisms in this kingdom are more primitive than those in the plant and animal kingdoms. Some fungi feed on other organisms and are, therefore, parasitic. Others eat dead or decaying organic material. Some fungi live in close association with algae; this is a mutualistic association, since both organisms benefit from it. The resulting organism is called a lichen.

Kingdom Plantae

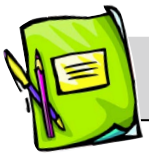
Organisms that belong to this kingdom are all multicellular, and most are photosynthetic. Photosynthetic plant cells possess chloroplasts. A few plants are heterotrophic; an example is the Venus flytrap. Plant cells have cell walls that contain cellulose. Cellulose gives rigidity and strength to plant tissue. Plants generally lack the ability to move; however, some plants have reproductive cells that possess flagella.

Plants are organisms whose cells are arranged into tissues and sometimes into organs. A tissue is composed of a "type" of cell that is specialized to perform specific functions. For example, vascular tissue in plants is designed to transport materials—food or water, for example. Simpler life forms that are multicellular do not possess the same degree of cell specialization and tissue development as is seen in plants.

Kingdom Animalia

About one million species of animals are known to exist on Earth today. Animals are multicellular heterotrophs. They generally possess the ability to move. They are not photosynthetic. Animal cells do not possess cell walls. The cells in an animal are organized into tissues, the tissues into organs, and the organs into organ systems.

This animal kingdom possesses great diversity. Sometimes the word *animal* is thought to be synonymous with the word *mammal*. In reality, mammals are only one group within the animal kingdom. Like mammals, sponges, worms, insects, coelenterates, amphibians, fish, reptiles, and birds are also animals. Not all animals have skeletons, not all have hair, and not all are warm-blooded. Some possess a nervous system, while others do not. Some possess brains, while others do not. Some animals live on land, and some live in the water or in the air.



Learning Activity 4.4: The Three Domains of Life

You will have an opportunity to apply what you have learned about the three domains of life by completing this learning activity.

1. Name the three domains that are currently used in biology to classify the life forms on Earth. For each domain, state the characteristics that distinguish it from the other two domains.

(continued)

Learning Activity 4.4: The Three Domains of Life (continued)

2. Complete the chart below for the Eukarya kingdom.

Eukarya Kingdom				
	Protista	Fungi	Plantae	Animalia
Cell wall (present or absent)				
Composition of cell wall (if present)				
Unicellular or multicellular				
Autotrophic or heterotrophic				
Motility				
Examples				

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 4.4. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned more about how living organisms are classified into groups. In particular, the three-domain system helps us to gain a better understanding of evolutionary relationships between groups of organisms. It can be used to classify organisms using more than just their physical characteristics. In the next lesson, you will look at examples of evolutionary change and how they illustrate relationships between organisms over time.

Assignment 4.4: The Three Domains of Life (15 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 4.

Part A

1. Each characteristic listed below is typical of organisms belonging to one or more of the six kingdoms that you have studied in this lesson. For each characteristic, write the letter corresponding to the kingdom (or kingdoms) that it describes or is associated with. Some characteristics may apply to more than one kingdom, but you need to give only one answer for each question. *(10 marks)*

The Six Kingdoms

A Bacteria

B Archaea

C Protista

D Fungi

E Plantae

F Animalia

Characteristics

____ 1. Cell walls made of chitin.

____ 2. All forms are multicellular, heterotrophic; most are motile.

____ 3. Prokaryotic cells.

____ 4. Mammals.

____ 5. Slime moulds.

____ 6. Live in extreme environments, such as very salty or very hot water.

____ 7. Eukaryotic cells, heterotrophic.

____ 8. Eukaryotic cells, autotrophic.

____ 9. Apple trees belong to this kingdom.

____ 10. Eukaryotic, unicellular.

(continued)

Assignment 4.4: The Three Domains of Life (continued)

Part B

2. Before biologists used a three-domain system for classifying living organisms, they used the six-kingdom system suggested by Carl Woese.

   Why was the three-domain system for classifying living organisms seen to be an improvement over the six-kingdom system? In what ways does the three-domain system help us to understand living things better? *(5 marks)*

Lesson 5: Evolutionary Trends

Lesson Focus

In this lesson, you will

- ❑ investigate an evolutionary trend in a group of organisms

  Examples: hominid evolution, vascularization in plants, animal adaptations for life on land . . .

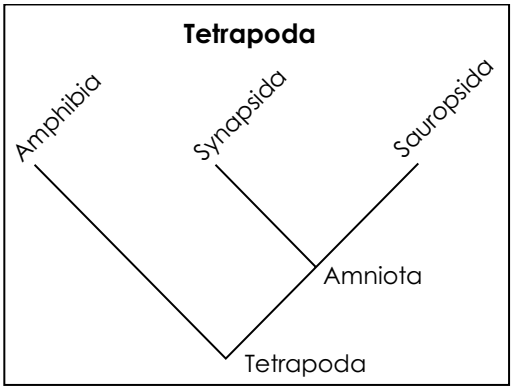
Introduction

As you have learned in previous lessons, physical characteristics are not the only traits used to classify organisms into groups. Genetic similarities and differences, biochemical clues, embryological development, and fossil evidence are some of the forms of evidence used to classify organisms into groups.

In Lesson 3 of this module, you learned about two classification approaches:

- **Traditional phenetic classification** separates the terrestrial vertebrates on Earth into four classes: amphibians, reptiles, birds, and animals. Fish, which are not terrestrial, are themselves divided into three classes: the jawless fishes, the cartilaginous fishes, and the bony fishes.
- **Cladistics** groups all terrestrial vertebrates into one taxonomic group: Tetrapoda. This group consists of two large subdivisions: Amphibia (animals such as frogs, salamanders, and toads) and Amniota (animals such as turtles, snakes, crocodiles, dinosaurs, birds, and mammals). Amniota, in turn, consist of two groups: Sauropsida (such as turtles, snakes, crocodiles, birds, and the extinct dinosaurs) and Synapsida (which are mammals). Furthermore, lobe-fin fish, which are closely related to amphibians, are grouped not with the fish, but with the amphibians. A cladogram of the Tetrapoda and its subgroups is shown in Figure 4.14.

Figure 4.14 ***Cladogram of the Tetrapoda***



In this lesson, you will look at graphic representations of these two different approaches to classification. These representations will show changes in organisms as they are believed to have occurred over time. In other words, you will look at evolutionary change as an important part of the knowledge used in classifying living things into taxonomic groups.

Hominid Evolution

The term *hominid* refers to the group to which humans and their ancestors belong. *Hominid* is actually an abbreviated form of the Latin family name *Hominidae*, which refers to *human*. A great amount of evidence indicates that modern humans share a common ancestor with modern apes. Hominids are the species on the human side evolving from that common ancestor. Based on the fossil evidence, it is currently accepted that the common ancestor of modern humans and modern apes lived between 5 and 15 million years ago.

The fossil record of early humans is understandably incomplete, since the process of fossilization rarely produces a result that can eventually be found. Becoming a fossil, then, is a rare event. Scientists can piece together the evidence that is available to increase their understanding of human evolution. Some knowledge comes, of course, from comparative studies involving modern apes and other modern primates less related to humans. Theories about human evolution continue to evolve as scientific knowledge increases through research.

Some people may find it frustrating that scientific thinking about human evolution continues to change over time, but that is due to the nature of science—ideas about life on Earth must change as new evidence comes forward to challenge earlier ideas. It may be confusing that some fossilized remains of a given species are referred to as near-hominid, suggesting that scientists are not sure whether that species is an ancestor of modern humans. That the evolutionary past occurred is an accepted fact, but our understanding of it depends on the evidence that we find of its occurrence. We are limited by what we know at any point in time. Theories in science are tentative because they depend on the evidence gained through research; as time goes by, we understand more and more about evolution. Our picture of what happened, and will continue to happen, is always getting clearer.

You will now look at current scientific thinking about the evolution of human beings. The species discussed below are understood from the hominid fossil record, except for *Homo sapiens*, to which modern humans belong. Only some species from the hominid fossil record are discussed so that you can gain a general understanding of human evolution. Remember, the hominid fossil record is vast and includes many species.

Resource Link

If you would like to investigate the hominid fossil record further, you can visit the following website.

University of California Museum of Paleontology. "The Emergence of Humans." *Understanding Evolution*. http://evolution.berkeley.edu/evolibrary/article/evograms_07.

Homo habilis

The *Homo habilis* species, whose name literally means handy man, was so named because tools have been found near its fossil remains. The dating of fossil remains and the artifacts found with these fossils have provided evidence that *H. habilis* existed approximately 2.4 to 1.4 million years ago. The specimens belonging to this species are quite variable in anatomy; the average height of these individuals was about 1.5 metres (5 feet) and the average weight about 45 kilograms (100 pounds). Studies of the brain cavity of these animals suggest that early forms of speech may have been used. Specimens of this species have been found only in Africa.

Homo erectus

Homo erectus, whose name means man who walks upright, lived approximately 1.8 million to 400,000 years ago, according to the dating of fossil records of this species. Individuals of this species were significantly more powerful physically than modern humans are, but their brain size was smaller. Their skeletons indicate they were able to walk on two legs efficiently. They probably used fire, as well as tools made of stone. Specimens of this species have been found in Asia, Africa, and Europe. There is evidence to suggest that the last populations of *H. erectus* cohabited with early *Homo sapiens* in what is now central Asia during the last tens of thousands of years of their existence. This cohabitation likely would have invited competitive behaviour, the outcome of which was to be determined by the species with the most resourceful intellect.

Homo heidelbergensis

The fossil evidence points to the *Homo heidelbergensis* species living about 500,000 years ago. The brain size in these individuals is intermediate between that of *H. erectus* and *H. sapiens*. The skeletons of these individuals indicate that they were less strong physically than *H. erectus* but significantly stronger than *H. sapiens*. Some fossils that have been found have been difficult to classify clearly as either *H. erectus* or *H. heidelbergensis* because of the strong similarity of these two species.

Homo neanderthalensis

The animals belonging to the *Homo neanderthalensis* species are sometimes referred to as Neanderthal man. They existed approximately 300,000 to 30,000 years ago. For the most part, they lived in cold areas of the world. Their limbs were short and thick. Neanderthals were very strong compared to modern humans. Their skeletons average about 1.67 metres (5 feet, 6 inches) in height. Along with their fossil remains, their tools and weapons have been found in abundance. They were primarily hunters and probably lived difficult lives centred on survival. They are the first hominids who buried their dead. Their fossils have been found mostly in Europe, but also in parts of Asia. Here again, there is abundant evidence to suggest that many populations of *H. neanderthalensis* cohabited with early *H. sapiens* in what is now central Europe during a large portion of their time on Earth. As with earlier cohabitation situations, competitive behaviour for food, other resources, and reproductive supremacy would dictate that one of these groups was to be eradicated by the other. The outcome was determined by the species with the greatest potential to endure and to reproduce.

Homo sapiens

Scientists now accept that members of *Homo sapiens* first appeared about 195,000 years ago. One type of early human, Cro-Magnon Man, lived about 40,000 years ago; in this culture, tools became more sophisticated, and sewing, carving, and sculpting became more common. Over the next 20,000 years, elaborate cave paintings were made, which indicate a growing appreciation of the importance of recording history and creating things of beauty.

During the course of human evolution, a number of physical characteristics have continued to change gradually. For example, the face, jaws, and teeth of hominids have become smaller and less robust as evolution has continued. Brain size has also continued to increase. Note that the brain size of Neanderthal man is somewhat misleading. It is correlated with the greater body mass of Neanderthal man, as compared to modern humans.

Over time, the skull of hominids has become less long and low. The brow ridges have become less pronounced and the forehead has continued to rise more sharply instead of receding toward the back of the head. The chin has become more prominent. The skeleton of modern humans is far more delicate than the fossils of any ancient hominids that have been found.

The Characteristics of the *Homo* Species chart in Figure 4.15 shows a possible evolutionary tree for the human species. Note that some of the hominid species discussed in this lesson are found in this chart, while others are not.

Figure 4.15 **Characteristics of the Homo Species**

Species	Skull	Time in fossil record	Characteristics
Homo habilis		2.4–1.4 million years ago	• Average brain had a capacity of 650 cm^3 • Used tools
Homo ergaster		1.8–1.2 million years ago	• Average brain had a capacity of 1000 cm^3 • Had thinner skull bones • Had humanlike nose
Homo erectus		1.8 million–400,000 years ago	• Average brain had a capacity of 1000 cm^3 • Had thinner skull bones • Used fire
Homo neanderthalensis		300,000–200,000 years ago*	• Average brain had a capacity of 1500 cm^3 • Buried their dead • Possibly had a language
Homo sapiens		195,000 years ago to present	• Average brain has a capacity of 1350 cm^3 • Does not have browridge • Has a small chin • Has language and culture

* Many sources suggest 300,000–30,000 years ago.

Photo credits: (1, 2, 4) Pascal Goetgheluck/Photo Researchers, (3, 5) KAREN/Sygma/CORBIS

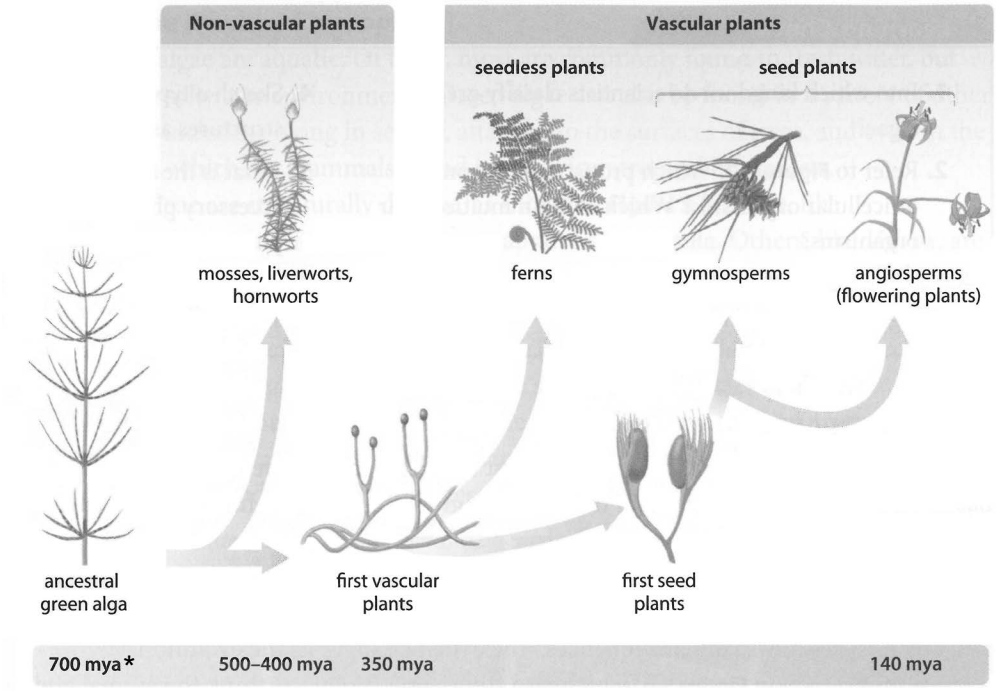
Source: Biggs, Alton, et al. *Glencoe Science Biology*. Columbus, OH: Glencoe/McGraw-Hill, 2009. 471.

Vascularization in Plants

Various forms of evidence indicate that the early ancestors of modern plants were freshwater, unicellular green algae. Gradually, plants developed the ability to live on land; a variety of adaptations have allowed terrestrial plants to deal with the temperature extremes and the shortage of water found outside aquatic habitats. You will now learn about how modern plants are classified and about how modern vascular plants have evolved.

Figure 4.16 shows the evolutionary development of four types of modern land plants, beginning with the mosses and ending with the flowering plants. The more ancient life forms are found at the top of the diagram, while angiosperms are the plants on Earth today that are thought to have evolved most recently.

Figure 4.16 **Developments in the Evolution of Land Plants**



* *mya* means million years ago.

Source: Dunlop, Jenna, et al. *Biology 11*. Toronto, ON: McGraw-Hill Ryerson, 2010. 94.

Classification of Modern Plants

The plants that exist on Earth today are either non-vascular plants or vascular plants. Vascularization is a trait that has enabled plants to exist in terrestrial environments successfully. Vascular tissues are specialized structures that allow the plant to carry water and food efficiently from one area to another. As a plant grows away from the soil, it is challenged with efficiently maintaining enough water in its stems and leaves, since water is constantly evaporating into the surrounding air. *Xylem* is the tissue that carries water within the plant, and *phloem* is the tissue that carries food.

There are significant differences between non-vascular and vascular plants:

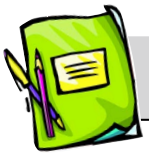
- **Non-vascular plants:** Three primary groups of plants do not possess vascular tissues: mosses, hornworts, and liverworts. Because these plants lack specialized transport tissues they must live in moist environments, and they never grow very tall because of their inability to carry water efficiently. Reproduction is possible in these plants only when water is present.
- **Vascular plants:** Vascular plants possess transport tissues. They are subdivided into two major groups, those that produce seeds and those that do not. Club mosses, ferns, and horsetails are vascular plants that do not produce seeds in order to reproduce. Seed-producing vascular plants are classified into five major groupings:
  - cycads
  - joint firs
  - ginkgos
  - pines and other cone-bearing plants
  - flowering plants

The Evolution of Vascularization

By tracing the evolution of modern plants, scientists can see that the ability to live on land brought with it challenges that were overcome over evolutionary time. Reproduction in terrestrial environments required the evolution of pollen, seeds, and flowers. The evolution of flowers allowed sexual reproduction between different individuals that grow at a distance from one another. This has allowed a greater degree of genetic mixing and has, therefore, been an evolutionary advance. As you have learned in previous modules of this course, asexual reproduction results in offspring that are genetically almost identical to their parents. Sexual reproduction, on the other hand, allows a greater combination of genetic material in the offspring; this increase in genetic variability allows for greater adaptation to terrestrial environments. This adaptability has, over evolutionary time, resulted in the great diversity of flowering plants on Earth.

The vascular tissues that have allowed terrestrial plant life to thrive have themselves continued to evolve and to become more specialized and sophisticated. Xylem is the tissue that allows the movement of water and dissolved minerals from the roots to the stems and leaves of vascular plants. Phloem is the tissue that allows the movement of carbohydrates from where they are made in the leaves and stems to where they are stored in the roots. Both of these tissue types have become quite variable in different groups of vascular plants. The arrangement and structure of vascular tissues has evolved to allow the flowering plants to exist in a great diversity of terrestrial environments.

Many traits seen in terrestrial plants have allowed them to thrive and diversify. The leaves of higher plants possess tiny stomata, which open and close to allow the movement of gases into and out of the leaf while also controlling water loss. A waxy cuticle layer present above the epidermal layer on the leaf also prevents water loss. Leaves of shade-loving plants are often broad to maximize the area exposed to the sun for photosynthesis. Leaves of plants in deserts are very small and thorn-like to minimize water loss. All these adaptations allow plants to exist in terrestrial environments.



Learning Activity 4.5: Evolutionary Development of Vertebrates

One evolutionary trend that clearly shows change over time is the development of the wide variety of traits that allow animals to live on land. As you have learned, life on Earth originated in the sea.

1. Do some research on the evolutionary development of the following five groups of vertebrate animals: fish, amphibians, reptiles, birds, and mammals. Compare the five groups of vertebrates by filling in the chart provided. Then use the information from your research to answer the questions that follow.

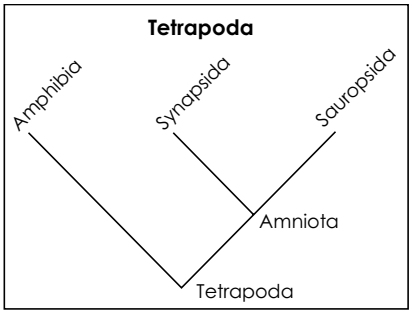
(continued)

Learning Activity 4.5: Evolutionary Development of Vertebrates (continued)

Evolutionary Development of Vertebrate Animals					
	Fish	Amphibians	Reptiles	Birds	Mammals
Primary habitat					
Where and how they reproduce					
How the young develop					
Warm-blooded or cold-blooded					
Limbs—structure and function					

a) Compare the reproduction of these five groups of vertebrates. In what way does this comparison show an increasing ability to thrive in terrestrial environments?

b) In what ways are fish different from the other four groups of vertebrates? Review Figure 4.14: Cladogram of the Tetrapoda from in this lesson (and reproduced below), and explain why fish were not included with the other four groups in the Tetrapoda group.



(continued)

Learning Activity 4.5: Evolutionary Development of Vertebrates (continued)

c) In what ways are mammals different from the other four groups of vertebrates? Referring to the cladogram again, explain why mammals are classified alone in the group Synapsida.

d) In what ways are birds and reptiles alike? Referring to the cladogram again, explain why birds and reptiles are classified together in the group Sauropsida.

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 4.5. The assignment details can be found after the Lesson Summary.

Lesson Summary

So, is a bird more closely related to a reptile than to a dragonfly? Dragonflies and most birds are capable of flight; however, this is not as important as the shared morphological features, biochemical similarities, and more recent common ancestor that birds and reptiles possess. Scientific classification schemes and naming systems continue to be modified as we learn more about the structure and function of living things and of the biosphere. The attempt to classify and name organisms does not change the organisms or the environments in which they live. Classification and naming helps us to make sense of nature.

In Module 5 of this course, you will learn more about the functioning of natural environments and human efforts to conserve and preserve them.

Notes

Assignment 4.5: Evolutionary Trends (10 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 4.

1. Flight is an ability seen in some insects, most birds, and a few mammals. Why are not all flying animals placed together in the same taxonomic group based on that important ability they share? *(5 marks)*

(continued)

Assignment 4.5: Evolutionary Trends (continued)

2. In 1959, anthropologist Louis Leakey discovered the fossil remains of an ancient primate belonging to the genus *Australopithecus* in Africa. At that time, it was believed that this primate was an ancient ancestor of humans. Current theories do not support that idea and, instead, claim that *Australopithecus* shared a common ancestor with modern humans but was itself an ancestor to modern chimpanzees.

   If scientific theories about human evolution continue to change (and they definitely will),

   - how can we say with any confidence that we know anything about human evolution?
   - will we ever be totally certain that scientific theories about human evolution are true?

   Explain your answers to each of these questions as clearly as you can. *(5 marks)*

Module 4 Summary

Congratulations! You have finished Module 4 of this course.

Submitting Your Assignments

It is now time for you to submit your assignments from Module 4 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 4 assignments and organize your material in the following order:

- ❑ Cover Sheet for Module 4 (found at the end of the course Introduction)
- ❑ Assignment 4.1: Biodiversity
- ❑ Assignment 4.2: North American Bear Species
- ❑ Assignment 4.3: Systems of Classification
- ❑ Assignment 4.4: The Three Domains of Life
- ❑ Assignment 4.5: Evolutionary Trends

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

Notes

Module 4 Summary

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- ❑ Assignment 4.5: Evolutionary Trends

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

Notes

Grade 12 Biology (40S)

Module 4
Organizing Biodiversity

Learning Activity Answer Key

Module 4:
Organizing Biodiversity

Learning Activity 4.1: Biodiversity

In this learning activity, you explained some of the concepts discussed in Lesson 1.

1. Define *biodiversity*.

   Biodiversity is the range of life in an area that is determined and sometimes quantified as the number of different species in that area.

2. Name and briefly explain the three aspects of biodiversity that you have learned about in this lesson.

   - Species diversity refers to the number of species found in an ecosystem.
   - Genetic diversity refers to the variety of genes or the traits that are expressed in a particular population of organisms.
   - Ecosystem diversity refers to the great variety of ecosystems that exist. An ecosystem is made up of both the living and the non-living factors in that area.

3. Why do humans study, compare, categorize, and name living things?

   Classifying living things satisfies our natural curiosity. It also helps us to gain a better understanding of living things.

4. What process has led to the great diversity of species on Earth?

   The process of evolution—change over time—has produced the great diversity of species on Earth.

Learning Activity 4.2: Case Study

For this learning activity, you read and answered questions about a case study, which helped you to clarify the meaning of species.

Questions

1. State two reasons why it could be argued that hawthorn maggot flies and apple maggot flies belong to the same species.

   It is not possible to distinguish these two types of flies from one another by looking at them. These two types of flies are not geographically isolated from one another and there is no physical separation between populations of these flies.

2. State two reasons why it could be argued that hawthorn maggot flies and apple maggot flies belong to two different species.

   There is only a 4 to 6 percent hybridization rate between hawthorn maggot flies and apple maggot flies. Each type of fly strongly prefers to mate and lay eggs on its own type of fruit. These two groups are genetically distinguishable; their genetic profiles are different.

3. Which conclusion, that hawthorn maggot flies and apple maggot flies belong to the same species or that they belong to two different species, is more strongly supported by the evidence that you have learned in this case study? Support your choice.

   It is clear that both groups belong to the species, *Rhagoletis pomonella*. But the fact that the two groups are genetically distinguishable from one another indicates that they could be two distinct species. Even though crossbreeding between these groups rarely occurs in nature, it does occur.

4. What further information would you need or would you like to have to increase your confidence in the conclusion that you reached in the previous question?

   The offspring that result from the two types of flies hybridizing could be studied to determine whether or not they are reproductively fertile. If they are fertile, that would provide evidence that the two groups belong to two different species. It would also be helpful to know the extent to which their genetic profiles differ. Even though hawthorn maggot flies and apple maggot flies are not geographically separated from one another, they seem to be fairly isolated reproductively from one another, since they both strongly prefer to mate and lay eggs on their own type of fruit.

Learning Activity 4.3: Systems of Classification

This learning activity gave you an opportunity to review what you had learned about systems of classifying living things.

1. Briefly explain the contributions that the following individuals made to classifying and naming living organisms:

   a) Aristotle

   He lived in fourth-century Greece and devised the first widely used system of classification by placing all organisms into one of two groups: plants and animals.

   b) Carolus Linnaeus

   He lived in the eighteenth century and developed the hierarchical system of classification consisting of these categories: kingdom, phylum, class, order, family, genus, and species. He based his groupings on physical traits of or resemblances between organisms. He also introduced binomial nomenclature, which provided a systematic way of naming species using Latin words.

   c) Ernst Haeckel

   In 1866, he suggested that microscopic life forms be classified into a new group: Protista.

   d) Robert Whittaker

   In 1959, he proposed the five-kingdom system of classification, placing plants, animals, fungi, bacteria, and protists into separate kingdoms: Plantae, Animalia, Fungi, Monera, and Protista.

   e) Carl Woese

   In the 1970s, he proposed the six-kingdom system of classification. The plant, animal, fungi, and protist kingdoms remained, while the bacteria kingdom was separated into two groups: the Eubacteria and Archaebacteria kingdoms. In the 1990s, he proposed that three domains be used: Eukarya, Bacteria, and Archaea.

2. Compare and contrast the two approaches used to classify organisms: phenetics and cladistics. How are they similar and how are they different? Explain.

   - *Phenetics* depends on morphology (physical characteristics) as the basis for classification. Physical traits of organisms whose fossils are studied can be compared to physical traits of living organisms. These comparative studies are used as the basis for grouping and naming organisms.
   - *Cladistics* depends on evolutionary relationship as the primary basis for classification. It classifies organisms based on the order in which they diverged from a shared ancestor.
   - Phenetics and cladistics have similarities and differences:
     - They are similar in that both are used to classify living things. Our understanding of living organisms depends on our ability to put them into meaningful groups and then comparing the groups.
     - They differ in their approach to classification. Phenetics depends on physical characteristics. Cladistics depends on evolutionary relationship.

3. Name and briefly explain three forms of evidence that biologists use to classify and name organisms.

   - **Fossil evidence:** Fossils are dated and compared, allowing biologists to piece together the path of evolutionary change. Morphological characteristics are carefully documented for later study.
   - **DNA evidence:** DNA and RNA sequences are studied and compared to gain a better understanding of how closely related different organisms are.
   - **Biochemistry:** Proteins are analyzed and compared; organisms that are closely related to one another are expected to share more protein sequences.
   - **Embryology:** The morphological characteristics of embryos of different organisms can be studied and compared to gain a better understanding of how closely related those organisms are.
   - **Morphology:** The physical characteristics of organisms can be compared. Similarities and differences can be used as the basis for classification decisions. These characteristics are very diverse, but include traits such as wing span, number of teeth, colour, and body mass.

Learning Activity 4.4: The Three Domains of Life

You had an opportunity to apply what you had learned about the three domains of life by completing this learning activity.

1. Name the three domains that are currently used in biology to classify the life forms on Earth. For each domain, state the characteristics that distinguish it from the other two domains.

   The three domains of life are the following:

   - **Bacteria:** Are prokaryotic, true bacteria (Eubacteria); possess cell walls made of a particular polymer (peptidoglycan); can be heterotrophic or autotrophic; can be aerobic or anaerobic.
   - **Archaea:** Are prokaryotic; live in extreme environments (in terms of salinity, temperature, oxygen level); have cell walls that do not contain peptidoglycan; can be heterotrophic (most) or autotrophic.
   - **Eukarya:** Are eukaryotic; have a membrane-bounded nucleus and membrane-bounded organelles; include protists, fungi, plants, and animals.

2. Complete the chart below for the Eukarya kingdom.

Eukarya Kingdom				
	Protista	Fungi	Plantae	Animalia
Cell wall (present or absent)	Present	Present	Present	Absent
Composition of cell wall (if present)	Some with cellulose	Chitin	Cellulose	None
Unicellular or multicellular	Both forms exist	Most multicellular	Multicellular	Multicellular
Autotrophic or heterotrophic	Both forms exist, some parasitic	Heterotrophic	Most autotrophic	Heterotrophic
Motility	Variable	Most not motile	Most not motile	Most motile
Examples	Amoeba, paramecium, euglena, slime moulds, algae, diatoms	Mushrooms, moulds, rusts, smuts, yeasts	Mosses, ferns, grasses, evergreen trees, flowering plants	Sponges, echinoderms, worms, fish, insects, reptiles, birds, amphibians, mammals

Learning Activity 4.5: Evolutionary Development of Vertebrates

One evolutionary trend that clearly shows change over time is the development of the wide variety of traits that allow animals to live on land. As you have learned, life on Earth originated in the sea.

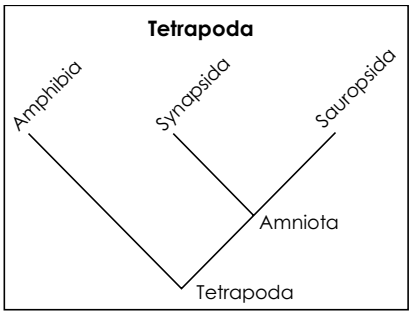
1. Do some research on the evolutionary development of the following five groups of vertebrate animals: fish, amphibians, reptiles, birds, and mammals. Compare the five groups of vertebrates by filling in the chart provided. Then use the information from your research to answer the questions that follow.

Evolutionary Development of Vertebrate Animals					
	Fish	Amphibians	Reptiles	Birds	Mammals
Primary habitat	Aquatic (marine or freshwater)	Aquatic before metamorphosis; aquatic/terrestrial after	Primarily terrestrial	Terrestrial and air	Primarily terrestrial
Where and how they reproduce	In water; external fertilization	In water; external fertilization	On land; internal fertilization	On land; internal fertilization	On land; internal fertilization
How the young develop	Hatch from eggs laid in water	Hatch from soft eggs laid in water	Hatch from leathery eggs laid on land; young are "hatched"	Hatch from hard eggs laid on land; young are "hatched"	Most develop within the mother's body; young are "born"
Warm-blooded or cold-blooded	Cold	Cold	Cold	Warm	Warm
Limbs—structure and function	Fins, including a tail	Four limbs develop during metamorphosis; tail before metamorphosis	Most have four limbs; snakes have none	Four limbs; two anterior limbs often used for flight	Four limbs—most forms walk/run, some forms swim

a) Compare the reproduction of these five groups of vertebrates. In what way does this comparison show an increasing ability to thrive in terrestrial environments?

Fish and amphibians are unable to reproduce without water because their eggs are externally fertilized in the water; reptiles, birds, and mammals can reproduce without water. The leathery eggs of reptiles prevent water loss. The hard eggs of birds prevent water loss and protect the chicks. The internal fertilization and internal development of the young inside the mother in mammals protects the young and allows a longer period of development. One of the challenges of a terrestrial environment is desiccation (dehydration). Another is the problem of how to put sperm in close contact with eggs. A comparison of the five groups of vertebrates shows an increasing ability to deal with these challenges.

b) In what ways are fish different from the other four groups of vertebrates? Review Figure 4.14: Cladogram of the Tetrapoda from this lesson (and reproduced below), and explain why fish were not included with the other four groups in the Tetrapoda group.



Fish do not have lungs for any portion of their life cycle. They are restricted to aquatic habitats. Their skeletons show adaptation to living in the water, with no need to walk, run, or fly. *Tetrapoda* means four feet; fish do not have four limbs during any portion of their life cycle.

c) In what ways are mammals different from the other four groups of vertebrates? Referring to the cladogram again, explain why mammals are classified alone in the group Synapsida.

Mammals are the only group in which the young develop inside the body of the mother; *Synapsida* refers to this mother–young connection before birth. Mammals are also the only animals to nurse their young. A few mammals (monotremes) lay eggs, but most do not. Marsupials carry their young in a pouch for most of the developmental period. Most mammals are placental—the young develop inside the uterus of the mother.

d) In what ways are birds and reptiles alike? Referring to the cladogram again, explain why birds and reptiles are classified together in the group Sauropsida.

Both birds and reptiles lay eggs on land. Both groups have scales on some portion of their bodies, and both have claws and often lack teeth. Both have internal fertilization, but the mother does not carry the developing young internally before birth.

Biology Videos

Module 4

1. Video - What is Biodiversity & Its Importance? Environmental Science for Kids | Educational Videos by Mocomi
2. Video - Learn Biology: Biodiversity Definition

GRADE 12 BIOLOGY (40S)

Module 5
Conservation of Biodiversity

Module 5:
Conservation of Biodiversity

Introduction

In the previous modules of this course, you have studied many topics related to genetics, evolution, and biodiversity. You have learned about natural selection, the mechanism of evolution. You have also learned a great deal about how scientists organize living things into groups based on life history, anatomy, and physiology. In studying these topics, you have gained a rich understanding of the biological world.

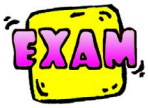
Human beings are animals and belong to the natural world, and yet we have unique abilities and motivations that allow us to cause dramatic change in the natural world. In this module, you will learn more about the choices human beings have and the choices we make in terms of how we use and affect living organisms and ecosystems. In Lesson 1, you will consider various reasons for maintaining biodiversity on our planet. In Lesson 2, you will learn more about strategies that can be used to conserve biodiversity. Lesson 3 will investigate methods that scientists use to monitor biodiversity. Finally, in Lesson 4, you will examine various issues related to the conservation of biodiversity.

Module 5 Assignments

When you have completed the assignments for Module 5, submit your completed assignments to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 5.1	Viewpoints on Maintaining Biodiversity
2	Assignment 5.2	Sustainability of the Boreal Forest
3	Assignment 5.3	Mark and Recapture Sampling
4	Assignment 5.4	An Environmental Issue in Manitoba (Research Paper)

Writing Your Final Examination



You will write the final examination when you have completed Module 5 of this course. The final examination is based on Modules 3 to 5, and is worth 20 percent of your final mark in the course. To do well on the final examination, you should review all the work you complete in Modules 3 to 5, including all the learning activities and assignments. You will write the final examination under supervision.

Lesson 1: Maintaining Biodiversity

Lesson Focus

In this lesson, you will

- ❑ discuss a variety of reasons for maintaining biodiversity

  Include: maintaining a diverse gene pool, economic value, and sustainability of an ecosystem

Introduction

Just as a species depends on its genetic diversity to adapt and survive, so the well-being of an ecosystem is related to the diversity of species living within it. In this lesson, you will explore the concept of biodiversity and consider several reasons for humans to maintain biodiversity.

What Is Biodiversity?

Lesson 1 of Module 4 began with the question, what is biodiversity? Before you examine why maintaining biodiversity is important, you will briefly review the meaning of the term.

Biodiversity is the range of life in an area that is determined (and sometimes quantified) as the number of different species in that area. Over time, the process of evolutionary change has led to the biodiversity that exists now on Earth. Species diversity, genetic diversity, and ecosystem diversity are all aspects of the larger concept of biodiversity. In this module, you will see that these three aspects are interrelated. Species diversity is inherently involved in ecosystem diversity. And species diversity is always linked to genetic diversity, since the definition of species is based on genetics.

Diverse Viewpoints on Maintaining Biodiversity

Before you begin to investigate possible reasons for maintaining biodiversity on Earth, you need to understand that the value assigned to each of these reasons lies in the beliefs of each person who is evaluating them. Your personal value system leads you to put more importance on some reasons than on others. And your personal value system may be significantly different from that of another person who is also working on this course.

Personal Values

Why should you consider personal values in a biology course? Isn't biology one of the sciences based on the gathering and evaluation of experimental data? Yes, biology is a science, but science is a tool that humans use to understand the world. Science uncovers truths that provide concrete pieces of knowledge about how the world works. But it is the application of that knowledge—our use of those truths—that leads to important ethical questions. How we make use of the truths/knowledge/understandings gained through science leads to questions of what is best, what is wise, and what is right.

In this lesson, you will be challenged to evaluate your own value system. Some of the reasons for maintaining biodiversity that will be discussed may seem more important to you than to others. That is as it should be. You will be challenged to understand the values held by other people as well. Sometimes you will agree with them, and sometimes you will disagree. When looking at the reasons for maintaining biodiversity, there is a diversity of human viewpoints. Challenge yourself to find your own viewpoint.

Reasons for Maintaining Biodiversity in the Natural World

Have you ever heard someone mourn the loss of a wild species? Have you ever met someone who values a wild species mostly in terms of what it can provide to human beings? Have you heard the ecological relationships in nature compared to a web of interlocking connections? These three questions briefly introduce the three broad reasons for maintaining biodiversity in the natural world: gene-pool diversity, utilitarian/economic and intrinsic value, and ecosystem sustainability. In many instances, these three broad reasons are also interconnected with one another.

Gene-Pool Diversity

The variety of genotypes and phenotypes present in a population can be referred to as the population's *gene pool*. The greater the variety of genotypes and phenotypes that exist within a population, the more diverse its gene pool is. Recall that evolution is the process of change over time; it occurs when environmental pressures make some genotypes and phenotypes more adaptive. Genes that result in beneficial traits remain in the gene pool, and genes that do not result in beneficial traits are reduced or eliminated.

If genetic diversity in a population of organisms is high, there is a good chance that some individuals will survive environmental change or selective pressures. If the genetic diversity in that population is low, very few of the individuals may survive the change. Keep in mind that environmental change is inevitable in the natural world. Genetic diversity within a population of organisms means that the population is more likely to survive environmental change or an outbreak of disease.

The importance of genetic diversity was discussed in Lesson 3, Module 3, using the case of industrial melanism studied by H. B. Kettlewell in England in the 1950s. Recall that *melanism* refers to the appearance of dark coloration in moths. The particular moth involved was *Biston betularia*, the common peppered moth. Originally, the most common phenotype of the species was a very light grey coloration. The majority of trees in the area had bark that was also very light in colour. The light coloration was advantageous to the moths because it helped them to blend in more effectively on the trunks of trees; less conspicuous than dark moths, the light moths were not as easily preyed upon by birds.

During the mid-1800s, industrialization in England resulted in the production of a large amount of air pollution; particulates in the air were deposited on the trunks of trees in the area and resulted in a significant darkening of those trees. This is an example of environmental change. The light-coloured moths did not survive as well as the dark-coloured moths in this new environment. If there had been no dark-coloured moths in the original population, the species might have been wiped out. But the gene pool contained genes that led to a variety of colorations; over time, the dark moths became more common and the light moths became less common. The species survived the environmental change and the accompanying selective pressures because of the diversity of its gene pool.

The argument in this case is that if biodiversity is not actively prioritized, species extinction may be the result. Species extinction itself leads to other potentially detrimental consequences, such as an increase or a decrease in the population sizes of other species, destruction of habitat, or ecosystem imbalance.

Utilitarian and Intrinsic Value

It has been argued that biodiversity should be actively maintained because of the economic value connected with it. In part, this consideration is based on personal human gain. But it is also based on consideration for future human generations. The loss of biodiversity in the present affects humans for generations to come.

Humans depend on biological species for a variety of material resources connected to food, clothing, shelter, medicine, energy, recreation, and so on. Maintaining biodiversity is wise in that it emphasizes the importance of preserving species and their traits, which directly or indirectly benefit human beings, as discussed in the following examples:

- **Agriculture:** In modern agriculture, the species of grain crops used for human food production have been derived from natural species. The cultivated varieties usually do not exist in nature and are genetically not very diverse. The natural varieties from which they came are far more diverse and are reservoirs of genes that code for traits that may become desirable to humans in the future. Maintaining natural biodiversity is important because improving cultivated species is an ongoing priority.
- **Medicine:** A great variety of medicines have been derived from natural species, and new discoveries continue to be made. Consider the example of penicillin, an early antibiotic that was first isolated from the common bread mould *Penicillium*. Many human diseases are caused by bacteria, and antibiotics have been very effective in the treatment of those diseases. Many species of organisms live in remote and unstudied parts of Earth; natural materials found in those organisms could effectively be used as medicines. When natural species are lost, the ability of humans to use chemicals produced by those species is lost as well.
- **Recreation:** Many human recreational activities also depend on the maintenance of species biodiversity. For example, recreational hunting and fishing depend on genetically diverse and stable populations of game species. The maintenance of genetic diversity in game species is, in many cases, related to human eradication of predatory species in those environments. If genetic diversity in game species becomes too low, those populations are very vulnerable to disease or environmental change. This particular argument is not as strong when the species being considered are non-game species. It is sometimes difficult to assign an economic value to a non-game species.

- **Eco-tourism:** An industry that has capitalized on the aesthetics of natural ecosystems is eco-tourism. Beautiful, interesting, mysterious, challenging natural environments have become attractive vacation spots for people who are able to pay to see and experience them. The aesthetic value of natural environments and the species in them have been translated into economic value. As a result, the value that humans place on natural environments can effectively lead to the protection of those environments.

So far in the discussion of maintaining biodiversity, you have learned about two general types of values that can be placed on natural organisms, communities, and ecosystems:

- **Utilitarian/economic value:** This type of value is of a practical or useful nature. For example, pickerel have utilitarian value because human beings eat them. Pickerel are also game animals, so they provide recreation to those who fish for them.

- **Intrinsic value:** This type of value refers to the inherent or natural qualities of the natural resource being considered. Natural beauty is an intrinsic value connected to places (e.g., native prairies) or to organisms (e.g., trumpeter swans). The intrinsic value of a particular part of nature lies, to some extent, in the eyes of the beholder; not everyone will assign the same value to a particular part of nature.

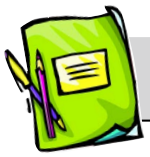
It may seem selfish to consider the intrinsic value of nature being of economic value as well. But many of the elements of nature—plants, animals, biological communities, and populations—are threatened by human activity, and yet belong to no one. Because they are often public goods, natural organisms and ecosystems may be vulnerable to destruction or depletion. To be protected, they must arguably be of some value. Intrinsic value is often most effectively respected if it is translated into economic terms as well.

Sustainability of an Ecosystem

The *sustainability* of an ecosystem refers to its stability and integrity over time. Recall that an *ecosystem* is a biological community and all the non-living factors that affect it. So, an ecosystem consists of all the life forms in a particular area, as well as the abiotic or non-living factors that affect those life forms. When the stability of an ecosystem is threatened, the survival of many species within it is threatened as well. The utilitarian and intrinsic value of those species and of the ecosystem as a whole is also in danger. The sustainability of an ecosystem depends on the biodiversity within it. If the species present in the ecosystem are altered significantly, the entire ecosystem is at risk.

There are many examples of ecosystems that have been threatened. Some types of ecosystems rebound or repair themselves more easily and faster than others. An example of a very fragile and vulnerable ecosystem is the tundra. Tundra ecosystems exist on Earth near both the North Pole and the South Pole. The tundra is a harsh environment in terms of both temperature and precipitation. Plants in the tundra remain small and close to the soil, which lies in a thin layer above permanently frozen ground called *permafrost*. When damage is done to the tundra landscape, repair is slow. The animals present are dependent on one another and interconnected by food webs that have evolved over the course of time. Damage to the landscape translates into damage to living populations. Some of the organisms, such as caribou, are also hunted by humans. Other qualities of the tundra ecosystem, such as the beauty of the snow in the pale winter light in the north, are of high intrinsic value even though it is more difficult to assign utilitarian or economic value to them.

One of the challenges to human efforts to maintain the sustainability of ecosystems is that many elements of natural processes and systems are very complex and difficult to understand. Human actions can have dramatic and lasting effects on natural ecosystems. It is wise to plan our actions with ecological implications and sustainability in mind.



Learning Activity 5.1: The Value of Natural Resources

Each of the following natural resources is arguably of value to human beings. For each natural resource listed, state whether you believe it is primarily of utilitarian value, intrinsic value, or both. Explain your choice.

1. Apples
2. Sunflowers
3. Natural gas
4. Golden eagles
5. Lake Winnipeg

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 5.1. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about three primary reasons for maintaining biodiversity in natural ecosystems: gene-pool diversity, utilitarian and intrinsic value, and ecosystem sustainability. You have also learned that decisions related to the use of natural resources involve value judgments. People have different viewpoints in relation to determining the value of natural organisms, communities, and ecosystems. In the next lesson, you will learn more about strategies that can be used to conserve biodiversity in the natural world.

Notes

Assignment 5.1: Viewpoints on Maintaining Biodiversity (20 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 5.

The following situations present dilemmas requiring you to make decisions regarding the value of natural ecosystems and living organisms. For each situation, you will try to see the dilemma from various viewpoints, and then explain which viewpoint most closely matches your own. Be sure to explain your reasoning as clearly and completely as you can.

1. A local developer wants to build a new Sportsplex and parking lot with five soccer fields, three hockey rinks, and four baseball diamonds. The ideal location for this Sportsplex includes a rare nesting site of the peregrine falcon (*Falco peregrinus*), which has been designated as an endangered species. For the past three decades, efforts have been made to re-establish the peregrine falcon population. *(6 marks—2 marks for each question)*

   a) From the developer's point of view, why is the value of the Sportsplex and parking lot greater than the value of the peregrine falcon nesting site? *(2 marks)*

   b) From an ecologist's point of view, why is the value of the peregrine falcon nesting site greater than the value of the Sportsplex and parking lot? *(2 marks)*

(continued)

c) Would you support or oppose the construction of the Sportsplex and parking lot? Why? *(2 marks)*

2. Another developer wants to use the land described in the previous situation (question 1) to develop a Welcome and Support Centre for Immigrant Families, which would provide a drop-in program, daycare centre, counselling services, and food hampers. Would you support or oppose this building proposal? Why? *(2 marks)*

(continued)

Assignment 5.1: Viewpoints on Maintaining Biodiversity (continued)

3. When a hydroelectric dam is placed on a river, a portion of the land above the dam is flooded and a reservoir is formed. The environment changes from a terrestrial one to an aquatic one. Consider a hydroelectric dam that is built on a river in central Manitoba. *(8 marks—2 marks for each set of questions)*

   a) From the builder's point of view, what benefits can be related to the building of the dam? Who will receive those benefits? *(2 marks)*

   b) From an ecologist's point of view, what benefits can be related to not building the dam? Are these values intrinsic or utilitarian? *(2 marks)*

   c) From a recreational point of view, what benefits can be related to building the dam? From a recreational point of view, what benefits can be related to not building the dam? *(2 marks)*

(continued)

d) Do you think the dam should be built? Explain. Do you need further information before you can answer that question? If so, what kind of information? *(2 marks)*

4. Of what utilitarian or intrinsic value is a trumpeter swan? Of what utilitarian or intrinsic value is a Canada goose? If both birds were endangered, which of them would you think should be saved first? Why? *(4 marks)*

Lesson 2: Strategies to Conserve Biodiversity

Lesson Focus

In this lesson, you will

- ❑ describe strategies used to conserve biodiversity

  Examples: habitat preservation, wildlife corridors, species preservation programs, public education . . .

Introduction

In the previous lesson, you learned about reasons why maintaining ecological biodiversity is important. In this lesson, you will learn about some strategies that people can use to accomplish that goal.

Conservation versus Preservation

At times, the terms *conservation* and *preservation* are used interchangeably. Although their meanings are related, these terms do not have the same meaning.

Conservation refers to the wise use of resources. Sound conservation practices are based on a firm understanding of the natural processes at work in the ecosystem. Conservation is aimed at preventing the depletion or extinction of resources. For example, conservation does not mean that hunting is prohibited; instead, hunting is controlled and monitored using sound ecological knowledge to set limits on hunting seasons and the numbers that can be hunted. Conservation areas often offer recreational opportunities such as hunting and fishing.

Preservation refers to the protection of resources. Often, it refers to the protection of a particular species in danger of extinction or of a habitat in danger of destruction. Wildlife preserves are typically areas in which human presence is limited and monitored.

Many organizations and government departments at the local, provincial, national, and global levels are concerned with ecological conservation and preservation. Globally, the World Wildlife Fund is an organization dedicated to preserving Earth's biological diversity. It is involved in monitoring pollution and wasteful consumption of resources. The Canadian Wildlife Fund actively advocates for the protection of Canada's wild species and wild places. It actively fosters educational programs to increase awareness of ecological issues. Provincially, Manitoba Conservation is concerned with many initiatives; it enforces hunting laws, funds research projects, protects non-game species, and educates the public about issues related to natural resources.

You will now look at four particular types of human actions that can help preserve and conserve natural resources: habitat preservation, establishment of wildlife corridors, species preservation, and public education.

Habitat Preservation

Recall that an organism's habitat is the particular area in which it lives, and that an organism depends on many aspects of its habitat for survival. For example, a panda bear depends on bamboo plants for food and cannot live in areas where bamboo is absent or scarce. Earthworms depend on rich soil that is neither too wet nor too dry. Reptiles such as snakes cannot survive in areas that are too cold, since they are ectothermic and cannot control their body temperature. Deciduous trees such as oaks cannot survive in areas with a short growing season, since they are relatively dormant in terms of photosynthesis when their leaves are lost during winter. These are all examples of how living organisms depend on their habitats for survival.

Tropical Ecosystems

Destruction of habitat is one of the most dangerous threats to the survival of living species around the world. This is particularly true in tropical areas. It has been estimated that over half of all species on Earth live in tropical regions. When human beings seriously disrupt ecosystems, as we have done in the tropics, habitats are destroyed or disrupted so severely that whole species of living things have become extinct or seriously threatened.

Why are habitats sometimes either destroyed or disrupted by human activity? In some cases, humans go into an area and take the resources for their use. For example, in the tropics, thousands of hectares of land are cleared for agriculture. The gigantic trees found in those areas have taken many years to grow and they survive in a relatively shallow layer of topsoil. When the trees are removed, the soil is thin and nutrient-poor. It sustains agricultural crops for only a very short period of time and then lies empty. Erosion is extremely common, carrying the soil into waterways.

When trees are cut down and agricultural crops grow in their place, the stability of the soil is threatened. The living things that depend on the tropical rain forest environment are threatened, since their habitats have been either destroyed or disrupted. Not all living species can simply "move somewhere else" when their habitats are no longer suitable. Many species decrease in number, and some actually become extinct.

Grassland Ecosystems

Before widespread agriculture and colonization took place in North America, much of the central part of this continent was covered by natural grassland or prairie. In areas where moisture was abundant, the grasses were tall and lush. In dryer areas, the short-grass prairie species predominated. Huge herds of bison inhabited the prairies in their native state. It has been estimated that there were about 50 million bison on the North American prairies in the early nineteenth century. Prairie dogs, coyotes, burrowing owls, wolves, and bears were all common species. The grassland ecosystem possesses a deep, rich layer of topsoil that supports a wide variety of herbaceous plants. It is a very productive ecosystem that, in its native state, depended on occasional fires to clear woody growth away so that succession could begin again.

When the central part of North America was settled, the ecosystems found there were changed. The native vegetation was plowed under and agricultural crops took its place. Bison were hunted nearly to extinction. The predators that thrived in the native prairies were not tolerant of human settlement and were not tolerated by human settlers. Over time, agricultural methods resulted in artificial fertilization of the soil and the implementation of various strategies to decrease soil erosion.

Many of the areas that were originally covered by native prairie grasses in North America are now used for agricultural crops and livestock. Many of the native species of those areas are either totally extinct or locally extirpated from their original habitats.

Polar Habitats

Polar habitats exist at both the North Pole and the South Pole. These regions include both water and land masses that are ice-covered. The largest land mass in the polar habitat is the continent of Antarctica. Many life forms exist in extreme polar environments, including penguins, seals, fish, polar bears, foxes, and krill.

One of the effects of rising global temperatures has been a decrease in large ice floes near Earth's poles. The habitat for species such as polar bears is actually shrinking. Polar bears depend on the presence of breathing holes in the ice, which seals use to breathe; the bears wait at the holes and then prey on the seals when they come up for air. As the number of these breathing holes shrinks due to global temperature increases, the number of polar bears that can survive in a given area is reduced.

As a top-level carnivore, the polar bear regulates the populations of organisms lower down on the arctic food chain, such as seals. Without a natural predator to control their numbers, seal populations could easily swell out of control. A disruption to one organism's habitat can easily produce a ripple effect through the remainder of its food chains.

Habitat preservation refers to human efforts to "set aside" areas that are critical to the survival of species living in them. Habitat preservation is based on the idea that the habitat of a species is necessary to protect the existence of the species. It is also based on human appreciation of the beauty found in natural ecosystems. Preserving habitats involves human beings protecting natural areas that support the existence of many wild species within them.

Wildlife Corridors

At times, habitats are fragmented or divided into smaller segments by human activities or human constructs, such as highways. In many cases, multi-lane highways divide habitats into two segments. For many living things, the segments are clearly separated, since the animals are unable to cross a highway. The populations of one species on either side of the highway are unable to interact and breed with one another. Each segment is smaller than the original area and can, therefore, support only a reduced diversity of living things.

An example of how a wildlife corridor can be built to bridge two segments of a divided habitat can be seen in Banff National Park in Alberta. At several locations, a fenced bridge of earth and grass has been built to arch across the highway. Many wildlife species are able to cross these bridges, thus restoring the habitat to its original size. Large animals, such as deer, elk, and bears, benefit substantially from the construction of wildlife corridors, such as the one shown in the photograph in Figure 5.1.

Figure 5.1 **Wildlife Corridor**

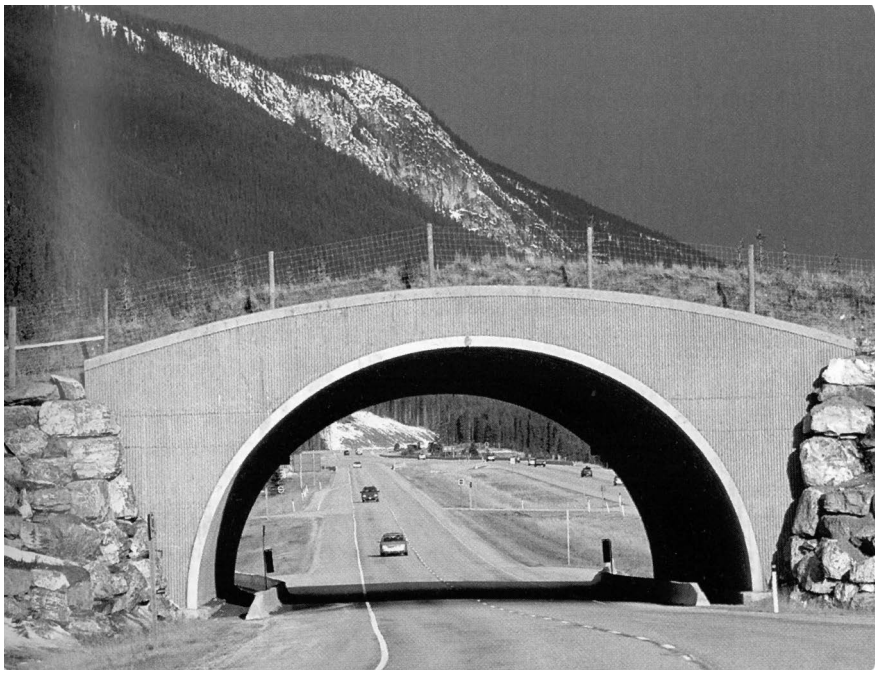


Photo credit: Alan Sirulnikoff/SPL/Photo Researchers

Source: Biggs, Alton, et al. *Glencoe Science Biology*. Columbus, OH: Glencoe/McGraw-Hill, 2009. 133.

Like many human efforts to maintain biodiversity, the construction of wildlife corridors is expensive. Such efforts require sustained, long-term commitment on the part of the agencies and individuals involved.

Species Preservation

Natural extinctions have always occurred during Earth's history. For example, *Tyrannosaurus rex* and many other dinosaur species that existed in the past have disappeared through natural extinction.

The extinctions that are of concern at the present time are those caused by human activities. Human nature leads us to change our environments—to make them more comfortable, more enjoyable, safer, or more productive. By making significant changes in environments around the world, we threaten the survival of species of living organisms in many areas of Earth today. Many species have already become extinct. One species that no longer exists on Earth is the passenger pigeon, once a common bird in North America. During the nineteenth century, passenger pigeons were aggressively hunted for their beautiful feathers, which were used in women's hats.

In some cases, species have become threatened; that is, their numbers have been reduced to low levels. These species may be in danger of extinction unless some intervention is attempted. For example, the number of bison in North America was reduced from very high numbers to fewer than about 1000 individuals before efforts were made to protect the animals from hunting and to preserve habitats for their survival. Bison were hunted for sport and for their hides, tongues, and meat.

Island-dwelling organisms are especially vulnerable to extinction at human hands. Island species have limited options for escaping to new areas when their natural habitats are destroyed or disrupted. Organisms on islands are threatened by human presence and actions. For example, humans sometimes bring pets, such as dogs and cats, which may prey on organisms in the natural island habitats. Humans may also introduce diseases to which the organisms have no immunity.

In the past, the primary reason for species extinction was overhunting or exploitation. Today, however, the main reason for species extinction is habitat loss. Efforts to preserve habitats are being made to prevent species extinction. Two organizations whose mission is to find solutions to environmental problems that threaten wild species on Earth are the Canadian Wildlife Federation and the International Union for Conservation of Nature.

Canadian Wildlife Federation

The Canadian Wildlife Federation (CWF), which began in 1962, is a charitable organization with about 300,000 members and supporters, whose mission is to ensure "an appreciation of our natural world and a lasting legacy of healthy wildlife and habitat by informing and educating Canadians, advocating responsible human actions and representing wildlife on conservation issues" (Canadian Wildlife Federation). CWF works in the areas of wildlife conservation, research, advocacy, and education. This organization produces a number of publications designed to bridge the gap between research and public understanding.

Resource Link

For additional information, refer to the following website:

Canadian Wildlife Federation. *About the Canadian Wildlife Federation*. www.cwf-fcf.org/en/about-cwf/.

International Union for Conservation of Nature

The International Union for Conservation of Nature (IUCN), founded in 1948, is the world's largest and oldest environmental network on a global scale, with a membership of more than 1000 organizations from 140 countries around the world. According to the IUCN website, IUCN's mission is "to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable." That is a very broad mission, one that is undertaken by nearly 11,000 volunteer scientists and experts around the world.

One of the initiatives of IUCN is the construction of its Red List of Threatened Species. For more than 40 years, IUCN has been determining the conservation status of many living organisms (plants and animals) on a global scale to determine which ones are most threatened with extinction. Its goal is to present objective, scientific, up-to-date information regarding the current status of threatened organisms. In so doing, it aims to highlight those organisms most in danger of extinction.

The IUCN Red List of Threatened Species places each organism that has been assessed on a scale designed to indicate extinction risk, ranging from least concern to extinct. The threatened categories include vulnerable, endangered, and critically endangered.

If you wish to find the classification of a specific organism, you can enter its name into the IUCN Red List database to find information. For example, the sea otter (*Enhydra lutris*) is classified as endangered on the IUCN Red List scale. The sea otter is found off the west coast of North America and the east coast of Asia, including Russia and Japan. About 30 years ago, sea otter numbers had been reduced by more than 50 percent, in part due to human activity, especially fur trading. Sea otters are very vulnerable to oil spills. They also are prone to drowning in commercial fishing nets. In some parts of the world, poaching still occurs. Being preyed upon by killer whales and being plagued by infectious disease are two other common causes of mortality for the sea otter. In Canada, sea otters are protected under the *Species at Risk Act* (Doroff and Burdin).

Resource Links

For additional information, refer to the following websites:

Doroff, A., and A. Burdin, *Enhydra lutris*. 2010. In: IUCN 2011. *IUCN Red List of Threatened Species*. Version 2011.1. www.iucnredlist.org.

International Union for Conservation of Nature (IUCN). *About IUCN*. www.iucn.org/about/.

IUCN. *The IUCN Red List of Threatened Species*. www.iucnredlist.org/about.

Public Education

The importance of public education with regard to ecological conservation and preservation issues can never be overestimated. Sound decisions are based on clear understanding. That understanding is based on thorough scientific research. If we are to conserve and preserve natural resources, we must first study natural systems and try to understand them as well as possible.

There are many examples of educational programs designed to share ecological knowledge with the public. Organizations such as CWF and IUCN (discussed earlier in this lesson) have educational programs. In Canada, governments at the municipal, provincial, and federal levels have committed resources and personnel to education programs aimed at increasing public knowledge of ecological concerns. Provincially, public school curricula have come to focus on environmental issues, not only in science, but also in the areas of social studies and human ecology. Young people are encouraged to consider environmental problems from different viewpoints and to weigh priorities before making decisions. Other educational programs intended to increase public awareness and understanding of environmental concerns include Project WILD, Project WET, and Canon Envirothon.

Manitoba Education: The Provincial Curriculum

To develop scientifically literate students, Manitoba's science curriculum is built upon five foundations for scientific literacy. One of the curriculum areas is Science, Technology, Society, and the Environment (STSE). The following five general learning outcomes have been identified as expectations for students related to the STSE foundation area.

STSE General Learning Outcomes

As a result of their Senior Years science education, students will

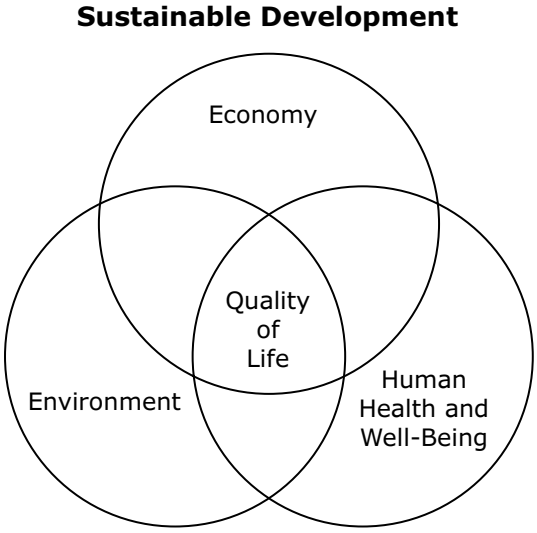
- describe scientific and technological developments—past and present—and appreciate their impact on individuals, societies, and the environment, both locally and globally
- recognize that scientific and technological endeavours have been, and continue to be, influenced by human needs and the societal context of the time
- identify the factors that affect health, and explain the relationships among personal habits, lifestyle choices, and human health, both individual and social
- demonstrate a knowledge of, and personal consideration for, a range of possible science- and technology-related interests, hobbies, and careers
- identify and demonstrate actions that promote a sustainable environment, society, and economy, both locally and globally

In Manitoba schools, understanding the complex interrelationships among science, technology, society, and the environment is an essential component of fostering increased scientific literacy. To achieve scientific literacy, students must also develop an appreciation for the importance of sustainable development:

> Sustainable development is a decision-making model that considers the needs of both present and future generations, and integrates and balances the *health and well-being of the community, the environment, and the impact of economic activities*. (Manitoba Education, *Grade 12 Biology: A Foundation for Implementation*, Section 1, page 6)

Figure 5.2 depicts this decision-making model.

Figure 5.2 ***Decision-Making Model***



Clearly, Manitoba's provincial curriculum addresses environmental conservation and preservation concerns. Students in Manitoba learn about ecological issues from Kindergarten to Grade 12.

Project WILD and Project WET

Project WILD is an interdisciplinary environmental and conservation education program for elementary and high school teachers and their students. The program offers a variety of indoor and outdoor learning activities to integrate directly into the school curriculum. It is possible for educators to become facilitators of this program and to share it with other educators. This program is supported by CWF.

Project WET is much like Project WILD, but concentrates on issues related to water ecosystems and species.

Resource Links

For additional information about these programs and their goals, refer to the following websites:

Canadian Water Resources Association (CWRA). *Project WET Canada*. www.cwra.org/branches/ProjectWet/.

Council for Environmental Education. *Project WILD*. www.projectwild.org/.

Project WET Foundation. *Project WET*. www.projectwet.org/.

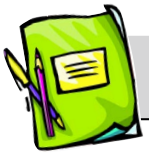
Canon Envirothon

Canon Envirothon is an annual competition in which winning provincial/state teams compete for recognition and scholarships by demonstrating their knowledge of environmental science and natural resource management. Envirothon offers both in-class curriculum and hands-on field experiences focused on ecology, natural resource management, and current environmental issues.

Resource Link

For additional information about this program, visit the following website:

Canon Envirothon. Home Page. www.envirothon.org/.



Learning Activity 5.2: Conservation and Preservation

This learning activity will help you to review what you have learned about strategies to conserve and preserve biodiversity.

1. Clearly explain the difference between conservation and preservation, both of which involve actions taken to protect natural resources.
2. Provide an example of how conservation practices and preservation practices can be used in combination to protect natural resources effectively.
3. Which approach to natural resource management is more effective, conservation or preservation?

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 5.2. In this assignment, you will consider the sustainability of the boreal forest, one of the most important biomes in Canada. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about the differences between the conservation of natural resources and their preservation. You have learned about a number of strategies that humans can use to protect natural resources, and you have considered the sustainability of the boreal forest biome. In the next lesson, you will learn about research methods that can be used to gain a better understanding of natural ecosystems. It is only through knowledge that we can implement effective conservation and preservation strategies.

Notes

Assignment 5.2: Sustainability of the Boreal Forest (20 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 5.

For this assignment, you will consider the sustainability of one of the most important biomes in Canada, the boreal forest. Read the following information and then answer the questions that follow.

The Boreal Forest: A Global Legacy*

What Is the Boreal Forest?

The boreal region—the largest biome on Earth—is one of three global forest types (along with tropical and temperate). Encompassing 33% of the Earth's forests, the boreal covers 11% of its surface. Fifty percent is located in Russia, 30% in Canada, and the balance is found primarily in Alaska and the Scandinavian countries.

Reflecting the fact that the boreal contains the world's most northern forests, it's natural that the origin of its name traces back to Boreas, the Greek god of the north wind.

Such a large forest ecosystem obviously contains a diverse range of habitats:

- The southern fringe includes the mixed forests of the southern boreal shield ecozone in the east and boreal transition parkland ecozone in the west.
- The heart of the boreal, a vast expanse stretching across Canada, is dominated by coniferous forest, peat-dominated wetlands and numerous lakes.
- The northern boreal region features the taiga, an ecological intersection where the forest meets the arctic tundra. The taiga contains a unique mix of boreal forests and peatlands, and open shrublands and meadows.

By far the most dominant tree species in the boreal forest is the conifer, which has adapted well to the cold harsh climate and the thin acidic soils. Characteristic conifers include black and white spruce, tamarack, jack pine and balsam fir. The most common deciduous species are aspen, balsam, poplar and white birch.

(continued)

* Source: Canadian Forestry Association. *The Boreal Forest: A Global Legacy*. Vol. 7. CFA Teaching Kit Series. Pembroke, ON: Canadian Forestry Association, 2005. 3–7. Available online at www.canadianforestry.com/kits/english/volume7-e.html. Reproduced with permission.

Assignment 5.2: Sustainability of the Boreal Forest (continued)

In this land of extremes, the total area affected by massive wildfires and other natural disturbances, such as insects and disease, is five times greater than those affected by timber harvesting. Instinctively, the boreal flora and fauna have adapted to the ravages and opportunities of nature.

Why Is Canada's Boreal So Important?

Around the world, the boreal is highly valued for its sustainable economic benefits, extensive recreational opportunities and breathtaking natural beauty. In Canada alone, the boreal provides petroleum products, peat, hydro-electricity and tourism dollars, and sustains over 7000 forestry businesses and 400 000 jobs.

Obviously, sustaining this valuable natural resource is a priority. Only 25% of Canada's forests, including the boreal, are managed for commercial use, and only one quarter of one percent is harvested annually. As mandated by law, all harvested areas are regenerated.

For centuries, people from all walks of life have lived in Canada's boreal communities, and as it did before the arrival of the Europeans, the natural wealth of this region helps sustain the traditional lifestyle of many of our Aboriginal people.

In terms of wildlife, the size, remoteness and variety of landscapes in Canada's boreal provide habitat to great numbers of some of the continent's largest species, including caribou, moose, bear and wolves, and billions of its smallest, such as migratory birds and butterflies. Since it holds more freshwater in its wetlands, lakes and rivers than any place else on Earth, the boreal also provides critical habitat for tens of millions of breeding waterfowl and shorebirds.

Up to three billion warblers, thrushes, sparrows, hawks and other land birds migrate to Canada's boreal region to nest each spring. As well, in dry years on the southern prairie breeding grounds, the boreal wetlands also act as a refugium for waterfowl populations displaced by drought.

To the benefit of both wildlife and human populations, the boreal forest plays a vital role in the regeneration of natural resources. It filters millions of litres of water daily, stores carbon, produces oxygen, rebuilds soils and restores nutrients.

Boreal forests also play a vital role in mitigating the impact of climate change. They store massive amounts of carbon and comprise one of the planet's few intact natural areas capable of buffering the changes in habitat that will be experienced by many northern species.

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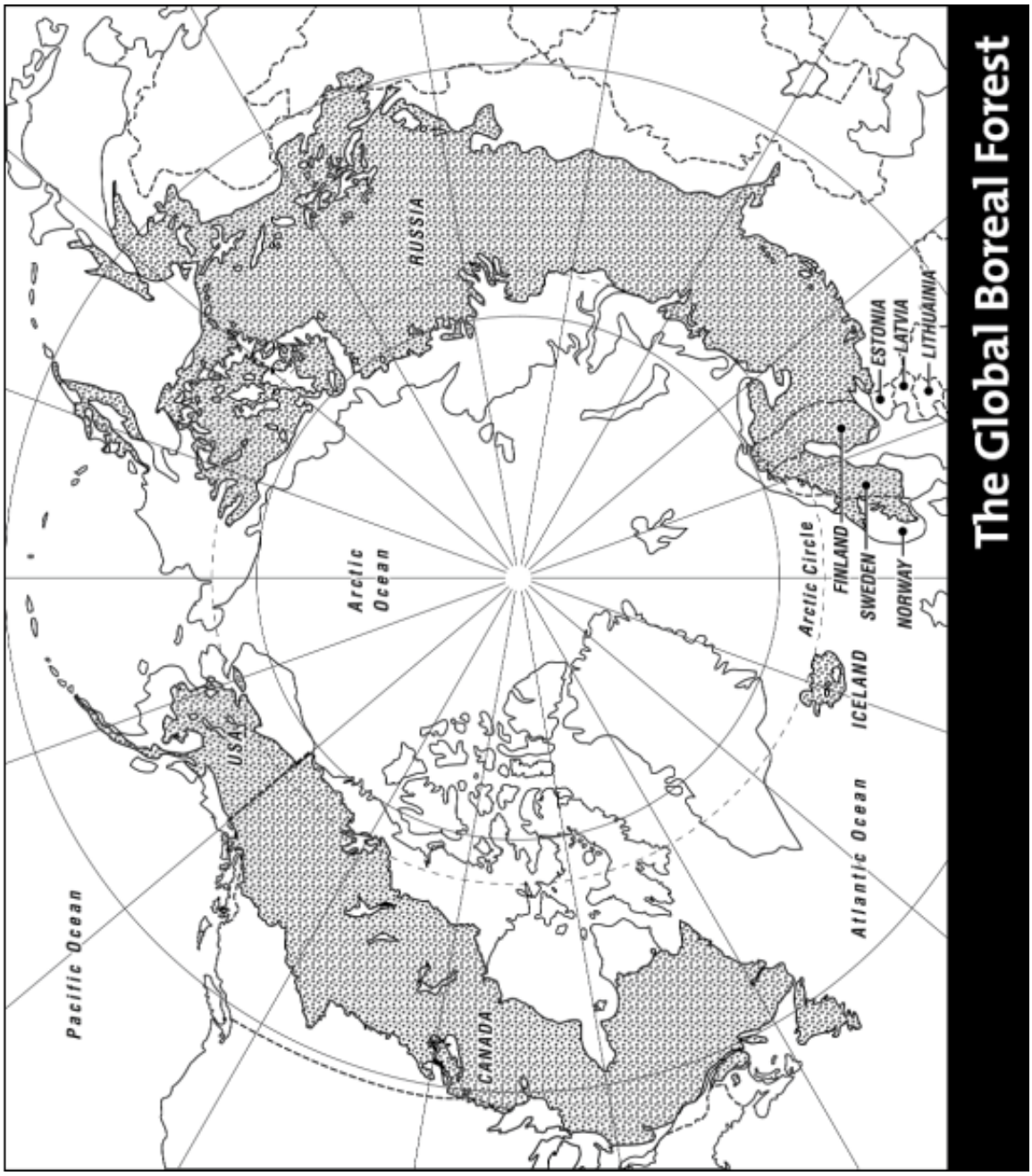
Assignment 5.2: Sustainability of the Boreal Forest (continued)



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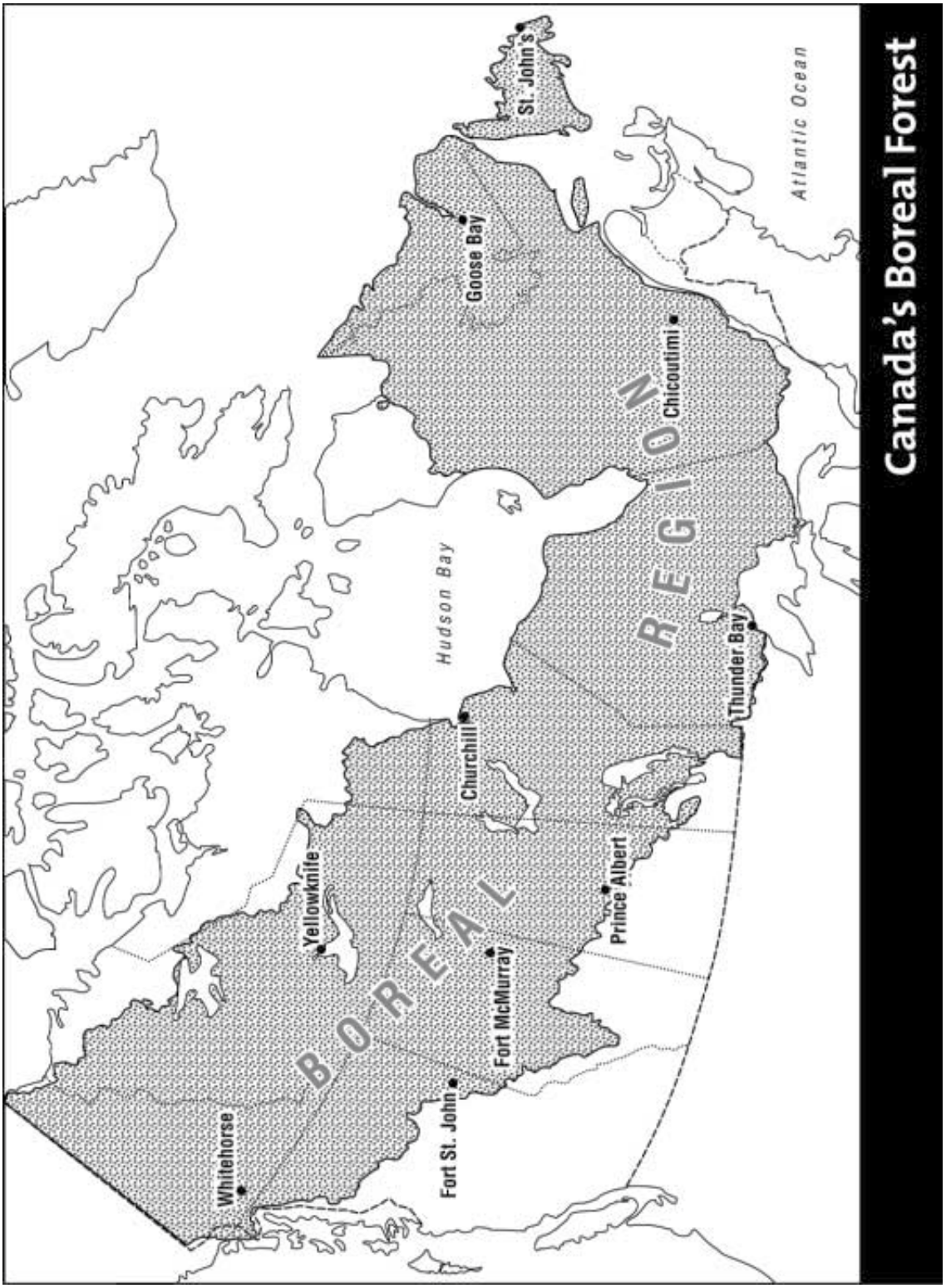
Assignment 5.2: Sustainability of the Boreal Forest (continued)



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Assignment 5.2: Sustainability of the Boreal Forest (continued)

Why Should We Conserve the Boreal?

Who Cares for Canada's Boreal Forest?

Since over 90% of Canada's boreal is publicly owned, our governments are its primary caretakers. In the south, provincial legislators are responsible. In the Yukon and Northwest Territories, Aboriginal land-claim negotiations and consultations between federal and territorial governments are ongoing. Trends indicate that boreal land-use planning, industrial regulation and wildlife management will continue in this manner, while the role and influence of Aboriginal government is expected to grow.

This is a critical time for Canada's boreal. Increasingly, nationally and internationally, this forest is recognized as a rare example of management of a large-scale ecosystem to ensure sustainability. Mandating protected areas and implementing best forest land-use management practices will go a long way towards achieving this goal—and the work has already begun. In 2004 the International Union for the Conservation of Nature and Natural Resources (IUCN), more commonly known as the World Conservation Union, called for greater protection of the boreal while recognizing that governments, Aboriginal and local communities, and conservation organizations have already made significant contributions, such as:

- Canadian and International Model Forest Networks and national forestry programs;
- national and other sustainable forest-management policies;
- park expansions and protected area strategies developed with—and often prompted by—Aboriginal people; and
- the Boreal Forest Conservation Framework that aims to protect at least half of the region in large interconnected protected areas, and supports world-class sustainable development in remaining areas.

Over the next few years, strategic land-use planning by the boreal provinces and territories will determine Canada's success for generations to come. The collective wisdom of our people and government will establish sound long-term management plans based on successful forest regeneration policies of the past. Canadians are encouraged to exercise their democratic right by participating in the conservation of the economic, environmental and cultural aspects of this irreplaceable—and highly valuable—natural resource.

(continued)

Assignment 5.2: Sustainability of the Boreal Forest (continued)

How Do Canadians Use the Boreal Forest Resources?

Centuries ago, voyageurs and European explorers plied the boreal's extensive waterways to explore new lands. Today, the boreal sustains a large part of the Canadian economy and fulfills many of our human needs.

Where the supply of natural resources dictates, oil and gas are extracted, peat is harvested, hydro-electricity is generated, and precious metals and minerals are mined. Timber is harvested for building supplies, paper production and numerous other by-products; trees are replanted on a continual basis. Of all the industrial sectors in the boreal region, forestry has made the most progress towards the development, adoption and implementation of leading-edge standards for sustainability.

In the south, significant land and water resources are dedicated to agriculture and transportation. Across this vast landscape—and through four seasons—recreation amenities abound.

For Canada's Aboriginal people, the boreal holds particular cultural significance and provides the many plants that hold special dietary, medical, economic and spiritual value.

How Big Is the Boreal?

Area covered by the global boreal: 6.0 million km^2 (compared to the area of Australia: 7.6 million km^2)

Number of trees planted in Canada's boreal in 2002: 609 million

Average age of trees in Canada's boreal: 100 years

Average forest-fire-return interval in Canada's boreal: 150 years

Portion of Canada covered by the boreal: 58%

Portion of boreal fibre available to support the Canadian forest sector (largest contributor to Canada's gross domestic product [GDP]): 75%

Portion of Canada's annual wood harvest from the boreal: about 50%

Portion of Canada's boreal currently ecologically intact: 70%

Portion of Canada's boreal currently protected from development: 10%

Portion of Canada's boreal subject to existing and proposed land-use planning: 60%

Portion of Canada's boreal containing water or wetlands: 30%

Number of people living in Canada's boreal: 4 million+

Country with the most certified forests and most certified boreal forests: Canada

Certified forests meet sustainable management standards, and their products carry a designation.

(continued)

The Boreal's Future

Challenges and Issues

Traditionally, due to their vast size and remote location, the boreal forests and associated wetlands have remained relatively intact and undisturbed by human activity. Resource development throughout much of the boreal ecosystem has been viewed as expensive and unnecessary. However, this trend is rapidly changing. Although 70% of Canada's boreal is not accessible by road, increasingly this undeveloped resource-rich wilderness is being tapped by industry.

The timber of the boreal—as in all forests—is a renewable resource. However, deforestation (permanent removal of forest) for agricultural use in some southern boreal locations is similar to the role of deforestation occurring in the Amazonian rainforest. Additionally, activities such as petroleum exploration, hydro-electricity generation, peat extraction, forestry and mining create disturbances (roads, pipelines, seismic lines, cut blocks) that result in cumulative impacts and permanent removal of parts of the forest. Such developments bisect various areas of the boreal, fragmenting and disturbing habitat and increasing the potential for conflict between wildlife needs and resource development interests.

Acid precipitation and climate change also continue to affect the integrity of the boreal. As well, residential development is on the increase, particularly throughout southern Ontario where, from the major urban centres of Toronto and Ottawa, the boreal can be accessed within a two-hour drive.

We Can Each Do Our Part

We can all help to conserve and protect Canada's boreal forest resources:

- Recognize the importance of forest communities and the people who live there; learn how they rely on the forest for income and the fulfillment of social, recreational and spiritual needs.
- Plant native tree species in the boreal.
- Protect riparian zones within the boreal.
- Do not litter or pollute, and make an effort to remove garbage when you see it.
- Travel by canoe, kayak and other people-powered watercraft, rather than motorized boats.
- Make known to elected representatives your wishes for boreal conservation and minimal fragmentation.
- Reduce, re-use and recycle to ensure our forest resources are utilized to their fullest.
- Support non-governmental and other organizations also working to conserve the boreal.

(continued)

Assignment 5.2: Sustainability of the Boreal Forest (continued)

Questions

1. Name the three global forest types. Where on Earth is the boreal forest found? *(2 marks)*

2. Name three types of coniferous trees found in the boreal forest in Canada. Name three types of deciduous trees found there. *(3 marks)*

3. Why is the boreal forest so important to breeding species of waterfowl and shorebirds? *(2 marks)*

(continued)

Assignment 5.2: Sustainability of the Boreal Forest (continued)

4. In what ways are boreal forests important in buffering the effects of climate change? *(1 mark)*

5. Name and briefly discuss **three** ways in which the boreal forest in Canada supports the economy and fulfills many human needs of Canadians. *(3 marks)*

6. In Canada, who owns and controls most of the land covered by boreal forest? Are there any exceptions? *(2 marks)*

(continued)

Assignment 5.2: Sustainability of the Boreal Forest (continued)

7. Name and briefly explain **five** ways in which modern human activity in the Canadian boreal forest threatens this ecosystem. *(5 marks)*

8. Do you live in the portion of Manitoba covered by boreal forest? If so, what can you do in your own life to conserve and protect this ecosystem? If not, what can you do in your own life to conserve and protect this ecosystem? *(2 marks)*

Lesson 3: Methods of Monitoring Biodiversity

Lesson Focus

In this lesson, you will

- ❑ select and use appropriate tools or procedures to determine and monitor biodiversity in an area

  Examples: field guides, dichotomous keys, quadrats, transects, mark and recapture . . .

Introduction

In the first two lessons of this module, you learned about some of the important reasons for valuing biodiversity in living ecosystems. You also learned about some of the strategies that we can use to ensure that biodiversity is protected and preserved. In this lesson, you will learn about some of the research tools and techniques that humans use to understand and monitor the biodiversity in the natural world. Some of these methods require specialized equipment and knowledge, while others can be put to use by anyone interested in gaining a better understanding of the workings of nature.

Methods of Identification and Nomenclature

Earlier in this course, you learned about the system of *binomial nomenclature*, the naming system first suggested by Carolus Linneaus in the mid-eighteenth century. Recall that each species is assigned a name consisting of two Latin words. The first word in the name indicates the organism's genus and the second word refers to the organism's species within the genus. Each species possesses a unique species name. This system is particularly useful for indicating species that are related, since they belong to the same genus.

By using the system of binomial nomenclature, we can

- identify relationships between organisms
- "tag" each species so that it is easier to describe and discuss particular organisms

Various tools and procedures can be used to determine and monitor biodiversity. *Field guides* and *dichotomous keys* are two tools commonly used to identify particular organisms in the field. Plant populations can be sampled with *transects* or *quadrats*, which are plots within which the number or type of species is counted in randomly selected areas. The size of a mobile animal population can be estimated using the *mark and recapture* technique in which the organism of study is tagged or banded.

Field Guides

Field guides are available in print and electronic formats for a great variety of plants and animals to help users identify living organisms in the field. Field guides of abiotic factors in natural ecosystems (e.g., rocks, clouds, animal droppings) can also be found; identification and naming of natural objects is the end result of using such guides.

Books

Some field guides are available in the form of books that help us identify living organisms, using basic characteristics of the organisms. Separate field guides exist for different types of organisms (e.g., ranging from fungi of the Canadian Prairies to songbirds of the Canadian Rockies).

Each particular field guide is typically divided into sections based on taxonomic groups. A field guide of birds in western Canada, for example, may contain a section on shorebirds, another on birds of prey, and another on warblers. Many field guides contain colour pictures with identifying physical features highlighted for the user. For example, the colour and pattern of the feathers on the undersides of the wings of hawks are shown to make it easier to identify a bird flying overhead.

Field guides of living things may also indicate the geographic range in which a particular species or group of species can be found. Some contain maps indicating summer range, winter range, and migratory routes, when they are important. A variety of information found in field guides can be used to identify an organism seen in nature. Physical markings and appearance, behaviour, vocalization, habitat, range, and other details of life history can all be used in combination to help identify organisms.

Field guides are especially useful for distinguishing between species that are very similar in appearance or behaviour. Typically, these species are found close together in the guides so that comparisons are easy to make. Natural variation within a single species can sometimes make identification challenging. Remember that some species such as dogs possess a number of subspecies within them, so the range of variation seen may be significant.

Online Field Guides

Some websites consist of online field guides. Although it may not always be possible to have access to the Internet while in the field, these websites are typically user friendly and offer illustrations, photographs, and audio recordings of the species identified.

Resource Link

For an example of an online field guide, refer to the following website:

eNature.com. Home Page. http://enature.com/home/.

This website provides detailed information about a wide diversity of wild species found in the United States and Canada, including

- birds, mammals, reptiles, and amphibians
- fish, seashells, and seahorse creatures
- arachnids and insects
- wildflowers and trees
- poisonous and dangerous organisms
- threatened and endangered organisms and native plants

Taxonomy, life history, distinguishing features, range, and behaviour are included in each species description. When an organism's vocalization is important in identifying it, this site also offers audio recordings.

Electronic Field Guides

Researchers are currently inventing prototypes of portable electronic field guides that can be used to identify species and record observations in the field. One such prototype, created by a research team funded by the National Science Foundation, is a smartphone application that helps users identify tree species. The user can photograph a leaf in question and then search the library of leaf images in a database of plant species. Several leaves are photographed for inclusion in the database; natural variation in terms of leaf structure for any one species requires a large sample size. In theory, each geographic area would have its own database with information regarding the species found there.

The software for this electronic field guide for trees will likely be available to the public in the future. It will probably first be used in museums where people can bring in sample leaves for identification.

Other electronic field guides are being developed to identify a variety of organisms. In Florida, the DARWIN (Digital Analysis and Recognition of Whale Images on a Network) research group is developing an automatic identification program for individual dolphins. This sorting system identifies dolphins based on photographs of their dorsal fins. Each individual dolphin has fins that have characteristic notches and nicks. This software is free and currently available to the public for download.

In the future, field guides such as these may have wide application and usefulness. A person in the field who has difficulty identifying an organism would be able to take a photograph of the organism and then send it to a central database site for identification.

Resource Links

For additional information on electronic field guides, refer to the following websites:

darwin.ec. Home Page. http://code.google.com/p/darwin-ec.

Eckerd College, Department of Computer Science. *DARWIN Project Home Site*. http://darwin.eckerd.edu/.

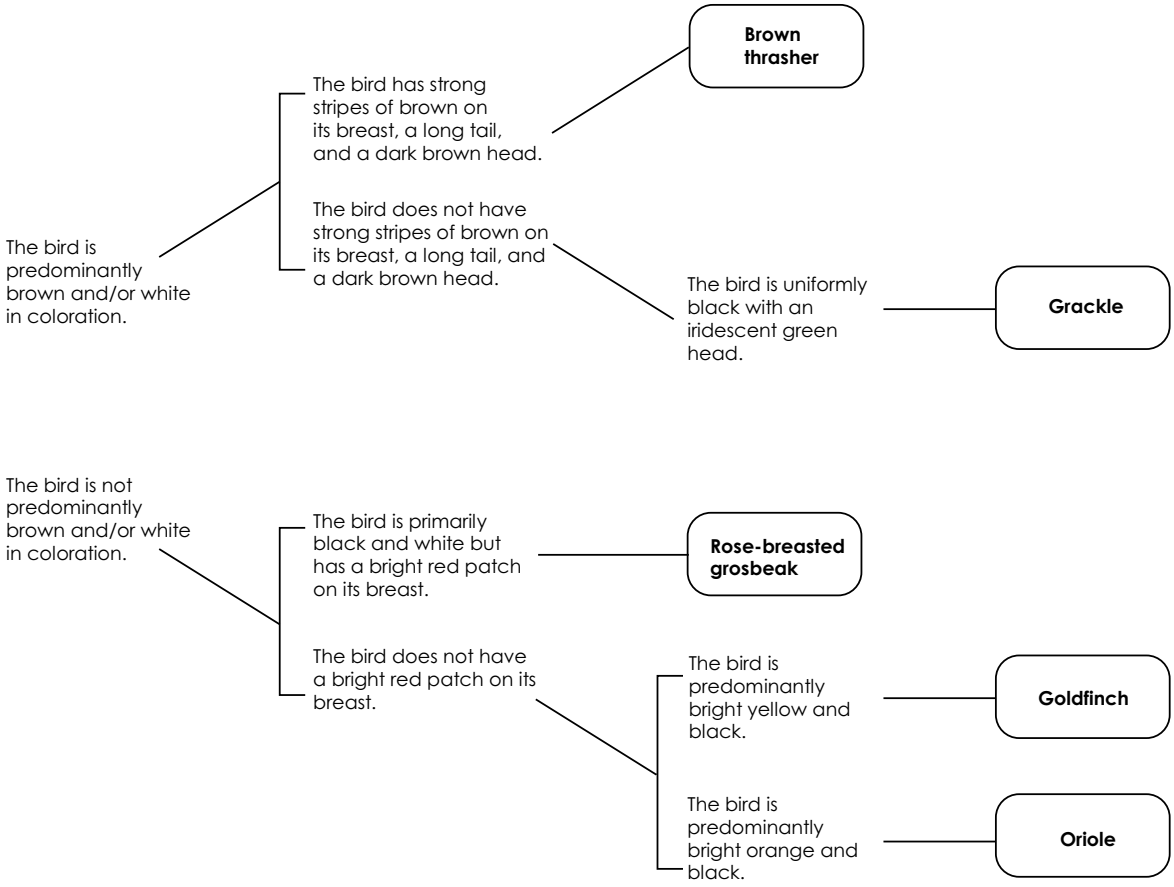
National Science Foundation. "Mobile Plant Field Guide Links Researchers and the Public." 1 July 2011. *NSF at Work*. www.nsf.gov/news/newsletter/jul_11/index.jsp.

Dichotomous Keys

A dichotomous key is another useful tool for identifying organisms. The word *dichotomous* comes from two Greek words that together mean divided into two parts. Dichotomous keys consist of a series of paired descriptions, beginning with very general details about a species (e.g., lives on land) and moving to more specific characteristics (e.g., has short, yellow hair). As users move through the list of statements, choosing the details that best describe the organism under observation, they will eventually find the organism's name. Typically, dichotomous keys concentrate on anatomical features and the appearance of the organisms being identified.

Figure 5.3 provides an example of a simple dichotomous key that could be used to distinguish five species of birds from one other and to identify a particular bird that is being studied. You do not need to be familiar with the particular birds here to understand the dichotomous key. Notice that, in the end, all five of the birds have been identified based on a series of choices made about their appearance.

Figure 5.3 ***Sample Dichotomous Key***



You will notice that the five birds identified above are not particularly similar. As a result, the sample dichotomous key is not very detailed in terms of the appearance of the birds. Also, it concentrates on colour. Other characteristics, such as beak size and shape, tail size and shape, song or call, habitat preference, or body size, could be used to help in identification.

The sample dichotomous key identifies the five birds by their common names; some dichotomous keys identify organisms by their scientific names. These keys can also be used to distinguish larger taxonomic groups, such as phyla, from one another. Dichotomous keys are powerful tools because they depend on the use of a series of choices that finally point to a particular "answer."

Quadrats

When a species is especially numerous or widespread, studying every individual organism (or even simply counting organisms) is an inefficient process. Instead, researchers study smaller sample areas from a habitat, with the assumption that these areas are a good representation of the larger ecosystem.

When studying small, stationary organisms such as plants, researchers often rely on quadrats. A *quadrat* is a square frame used to mark the boundaries of a sample area. It is often wooden or metal, and about one square metre in area. Researchers observe the different species within the quadrat, note their numbers and distribution, and record any changes over time. Sometimes, details about the environment such as soil type or the amount of sunlight and/or shade present in the quadrat will also be noted.

Since quadrats provide information on only a sample of a habitat, it is important to randomize the placement of quadrats to eliminate any bias. Often, an entire habitat will be divided into a numbered grid system, and researchers will randomly generate numbers to select the areas they will observe.

In 2004, the Living Prairie Museum, a tall grass prairie preserve located in Winnipeg, used quadrats to study the different types of plant life growing in the preserve. Sample areas in the preserve were randomly selected and observed over a period of six months.

Resource Link

To see the observations made in the Living Prairie Museum study, visit the following website:

Living Prairie Museum. "Virtual Prairie Quadrats." *The Living Landscape*. 2005. www.livingprairie.ca/livinglandscape/quadrats/index.html.

Transects

Plant populations within a habitat can also be sampled with *transects*. In this case, a series of lines is randomly identified within the habitat and the species that lie along those lines are identified, counted, and tallied. As a result, information is gathered about which species are present and how numerous they are within that habitat.

Two types of transects can be used:

- **Line transects:** With the use of this method, samples are studied at regular intervals along a line. Any species touching the line is recorded along the entire length of the line. This is an example of *continuous sampling*. In other cases, the presence or absence of a species along the line is recorded. This is an example of *systematic sampling*. Sometimes the particular line used is chosen because it cuts through an environmental gradient that is being studied. The line may pass through areas of heavy shade into areas of full exposure to the sun. It is important that the lines used be carefully chosen before the study is completed.
- **Belt transects:** Belt transects are similar to line transects except that a wider band (or belt) along the transect line is studied. At times, a series of quadrats is studied along the transect line. Sometimes the quadrats studied are consecutively located along the transect line, and sometimes they are located at intervals along the line. Those intervals may either be constant in length or of randomly chosen lengths.

Mark and Recapture

Mark and recapture is another method of studying the types of organisms present and their relative abundance in a particular habitat. This method is used to study animal species that are very mobile, numerous, or spread over a large habitat, so that examining every individual animal is not feasible. A sample of animals is captured and studied. Each animal in the study is then marked somehow and released back into the habitat. For example, if field mice are being studied, the animals may have the inside of their left ears marked with black ink before they are released. Every animal in the sample is marked in exactly the same way before it is released.

Once the sample has been released and given time to mix among the population, another sample is taken. In the second sample, each mouse captured is identified as either a marked mouse or an unmarked mouse. The total number of marked and unmarked mice is carefully recorded. This comparison of marked and unmarked individuals gives a good idea of the actual population size in the habitat being studied.

Example: Mark and Recapture of Field Mice

An example will help clarify the usefulness of the mark and recapture approach.

Assume that the first sample size is 100 mice. All 100 mice are studied and marked before they are released back into the habitat. Once the first sample has been taken and the mice released, a second sample is collected. This time, 200 mice are collected and 40 of them are found to be marked. That means that 160 of the mice in the second sample are not marked. You can assume that the ratio of marked to unmarked mice in the second sample is the same as the ratio of marked to unmarked mice in the first sample.

$$\text{Marked}^1 : \text{Unmarked}^1 = \text{Marked}^2 : \text{Unmarked}^2$$

$$100 : \times = 40 : 160$$

OR

$$\frac{100}{\times} = \frac{40}{160}$$

$$\frac{100}{\times} = \frac{1}{4}$$

$$\frac{100}{400} = \frac{1}{4}$$

$$\times = 400 = \text{Unmarked Mice}$$

100 Marked + 400 Unmarked = 500 Total Population

In the habitat being studied, there is a total population of 500 mice.

Sources of Error in Mark and Recapture

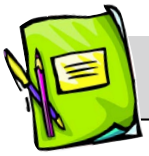
Mark and recapture is a powerful technique because it provides a way of estimating population size in a wild population. The type of marking used depends on the species. Some animals are given bands around their legs, collars, or tags. It is important that the marking device or technique used does not affect the survivability of the individual organisms.

Sources of error in the mark and recapture method include the following:

- Depending on the time between samples, new births or deaths may have affected the population numbers.
- If inappropriate devices or processes are used to mark captured animals, the marked animals would be less likely to survive to be recaptured. Marking may affect an individual's chances of survival (e.g., causing infection, reducing mobility, attracting it to predators).

- Some animals may become "trap happy" and allow themselves to be captured, especially if traps are baited with food.
- Other animals learn from their first capture and are less likely to be recaptured.

The research results from a mark and recapture study should explain possible sources of error.



Learning Activity 5.3: Transect and Quadrat Sampling

In this learning activity, you will practise using two methods of sampling population size: *transect sampling* and *quadrat sampling*. The third method of sampling, *mark and recapture*, is addressed in the assignment for this lesson.

Materials

For this learning activity, you will need a textbook, a ruler, a pencil, and a microscope cover slip. A cover slip is a very thin plastic or glass square used to cover microscopic specimens. If it is not possible for you to get a cover slip, use a square (2 cm x 2 cm) piece of cardboard. Instead of looking through the cover slip, you will trace around the cardboard square.

Part 1: Transect Sampling

1. Select one page at random from your textbook.
2. Hold the ruler flat over the page at a height of 10 cm. Close your eyes and drop the ruler on the page.
3. Slide the ruler so that it extends the length of the page (top to bottom). One side of the length of the ruler is the transect line. Choose either the left or right side of the ruler.
4. Count the number of letter *e*'s (small *e* and capital *E*) along the transect line. Count all the *e*'s that touch the transect line. Record that number in a data table, such as the one that follows.

(continued)

5. Repeat Steps 1 to 4 an additional four times, each time selecting a new page at random from your textbook. (In total, you will use five different pages from the textbook.) Record your data after each trial.

Data Table	
Trial	Number of Letter *e*'s and *E*'s
1	
2	
3	
4	
5	

Part 2: Quadrat Sampling

1. Obtain either a microscope cover slip or a 2 cm x 2 cm piece of cardboard. This is the quadrat.
2. Select a page at random from your textbook.
3. Hold the cover slip or cardboard about 10 cm above the textbook page. Gently toss the cover slip or cardboard onto the page. If you are using cardboard, carefully and lightly trace around it using a pencil.
4. Count the number of letter *e*'s (small *e* and capital *E*) that fall entirely or partially within the area covered by the cover slip or surrounded by the square. Record the number in your data table.
5. Repeat Steps 1 to 4 an additional four times, each time selecting a new page at random from your textbook. (In total, you will use five different pages from the textbook.) Record your data after each trial.

Data Table	
Trial	Number of Letter *e*'s and *E*'s
1	
2	
3	
4	
5	

(continued)

Learning Activity 5.3: Transect and Quadrat Sampling (continued)

Analysis

1. Calculate the average number of letter *e*'s (small and capital combined) on a page of your textbook.
   a) Using the transect method:
   b) Using the quadrat method:
2. Calculate the average number of letter *e*'s (small and capital combined) in your textbook by multiplying the average number of *e*'s per page by the number of pages in the textbook.
   a) Using the transect method:
   b) Using the quadrat method:
3. Compare the transect method estimate and the quadrat method estimate of the number of *e*'s (small and capital) in your textbook. Why might the two estimates differ?

When you have completed this learning activity, compare your responses with those provided in the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 5.3. The assignment details can be found after the Lesson Summary.

Lesson Summary

In this lesson, you have learned about several methods that can be used to estimate, monitor, and understand biodiversity. One of the most important things that you have learned about sampling techniques is that the sampling must be as random as possible. You have also learned that the sample size should be as large as possible and that it is best to have as many trials as possible. When trials are numerous, large, and random, the results are more meaningful and are a more accurate reflection of what is really going on in the natural world.

In the next lesson, the final lesson of this course, you will study a particular issue that relates to the conservation of biodiversity. You will put to use much of the knowledge you have gained in the first three lessons of this module.

Notes

Assignment 5.3: Mark and Recapture Sampling (20 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 5.

It can be difficult to determine the exact size of wild animal populations. This is why biologists use a variety of sampling strategies to estimate the size of populations in an area. Mobile animal populations can be estimated by using the mark and recapture method. This method involves tagging, marking, or banding the animals being studied.

Like the transect and quadrat methods of sampling, the mark and recapture method uses random sampling procedures. Care must be taken to ensure that randomness occurs when the sampling is performed; otherwise, erroneous population estimates will result. Biologists can then determine, by repeating sampling procedures over time, whether a population is growing or declining.

Materials

You will need an opaque jar or coffee can with a lid, about ¼ cup of uncooked white rice grains, a felt-tipped marker, and a calculator.

Procedure

1. In this exercise, the ¼ cup (50 mL or 55 grams) of white rice represents an animal population. You do not know how many grains of rice are in this measured amount of rice, just as you would not know the size of the wild population of animals that was being studied in a particular habitat. Place all the rice in a jar or can, and then take out 100 grains and colour each grain with a marker. Allow the marked rice to dry well, and then place all the rice, marked and unmarked grains together, back into the jar or can.
2. Shake the container well. Without looking into the container, reach in and remove 50 individual rice grains. Count how many of the 50 grains are marked and how many are unmarked. Record those numbers in a data table. Return the 50 grains to the rice container and shake it well.
3. Repeat Step 2 four more times. Record your results in your data table. You have "recaptured" a total of five times from the wild population.
4. Calculate the average number of marked grains (out of 50 possible grains) for the five trials that you conducted.

(continued)

Assignment 5.3: Mark and Recapture Sampling (continued)

5. Count all the rice grains in the container, both marked and unmarked grains together. Record this number in your data table. *(6 marks)*

Data Table		
Step	**Number**	
Number of rice grains initially marked	100	--
Trial 1 (total of 50)	# marked:	# unmarked:
Trial 2 (total of 50)	# marked:	# unmarked:
Trial 3 (total of 50)	# marked:	# unmarked:
Trial 4 (total of 50)	# marked:	# unmarked:
Trial 5 (total of 50)	# marked:	# unmarked:
Average of 5 trials	# marked: A =	--
Actual total number of grains	B =	--

Analysis

1. Calculate the estimated size of the rice population, using the following formula: *(2 marks)*

$$\frac{100}{\text{Estimated Population Size}} = \frac{A}{50}$$

OR

$$\text{Estimated Population Size} = \frac{100 \times 50}{A}$$

(continued)

Assignment 5.3: Mark and Recapture Sampling (continued)

2. Compare your experimental estimated population size to the actual number of grains in the ¼ cup of rice (which was the original "population"). *(2 marks)*

3. Calculate the percent error in your estimate, using the following formula: *(2 marks)*

$$\text{Percent Error} = \frac{\text{Estimate} - \text{Actual}}{\text{Actual}} \times 100$$

4. How do you explain the experimental error in your estimate of the population size in this exercise? Name at least two sources of experimental error that you believe could have affected your results. *(2 marks)*

(continued)

Assignment 5.3: Mark and Recapture Sampling (continued)

5. Name at least **two** changes that you could make to the procedure used in this exercise that you believe would result in a smaller percent error in the results. Briefly explain why you would make each of the changes that you suggest. *(4 marks)*

6. Name **two** ways in which the steps in this experimental procedure differ significantly from an actual mark and recapture done with a real wild population. *(2 marks)*

Lesson 4: Issues in Conservation

Lesson Focus

In this lesson, you will

- ❑ investigate an issue related to the conservation of biodiversity

  Examples: heritage seeds, water quality in Lake Winnipeg, land-use designations, hydroelectric development . . .

Introduction

In the three previous lessons in this module, you have studied reasons for maintaining and protecting biodiversity, strategies for conserving biodiversity, and methods that can be used to measure, monitor, and understand biodiversity. In this lesson, you will look at a particular issue of your choice that relates to the conservation of biodiversity. As this is an extremely broad topic, this lesson will focus on a number of possible issues from which you can choose. Remember to apply the knowledge you have gained throughout this course as you do an in-depth study of a particular ecological issue that interests you.

Human Decisions Regarding Environmental Issues

Both positive and negative examples of human interventions that affect living ecosystems can be identified across our planet, from polar to equatorial regions and from the deep sea to the highest mountaintop. Human beings are animals and, therefore, belong to the natural world. Like other organisms, we have an impact on our environment. However, it is apparent that our influence on the natural world is more dramatic than that of any other species. Our intelligence has resulted in the invention of many types of technologies that we use for many purposes, such as survival, research, comfort, human health, convenience, and enjoyment.

A number of factors influence human decisions regarding natural ecosystems. You have studied some of these factors in previous lessons. Societal, environmental, and economic factors all influence human decision making about the environment. How different people view the relative importance of these factors depends heavily on their value systems. People vary tremendously in terms of what they value, whether it is their own comfort, the health of a natural ecosystem, or the survival of a wild species.

And yet, people must come to some consensus when making important decisions. This is particularly problematic, but essential, in the case of global environmental issues.

Take a Stand: Scenarios

Two issues that require people to analyze their value systems in order to make decisions are discussed in the two scenarios that follow. Read and reflect on each scenario. For each issue, think about your position, concentrating on your reasons for thinking and feeling as you do. Try to analyze your own priorities and motivations.

---

1. Fish Now or Later?*

   Mike has made a living for himself and his family for the last 20 years as a commercial fisherman on Lake Winnipeg. He recently purchased a new, larger fishing boat. The payments on his boat are high, but Mike and his crew can work more safely and efficiently.

   Mike's neighbour Ramon is a freshwater biologist who works for the government. He has been studying fish populations in the lake over the past 10 years and is supporting a large reduction in the amount of commercial species (pickerel and whitefish) that can be caught in a year. Ramon says, "My research shows that the number of fish in the lake is declining. We need to cut back on the quotas assigned to fishers."

   "I can't have my quota cut back," replies Mike. "I have to make my payments on my boat, and have a family to support. My crew needs their jobs as well. Why don't you do something about the pollution in the lake that is causing the fish stocks to decline?"

   Ramon replies to Mike's concerns by saying, "If we don't act now, there won't be any fish left in a few years. The fish are at great risk. Look what happened to the East Coast cod fishery."

   "There still are lots of fish in the lake," answers Mike, "and I expect to catch my fair share, which is why I bought my new boat. How else can I pay for it? How else can I earn a living?"

   Where do you stand on the question of cutting back on fishing quotas?

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* Source: Greene, Alanda. "Where Do You Stand?" *Green Teacher 54* (Winter 1997–98): 19–21. Adapted with permission. For information about this non-profit Canadian magazine, visit www.greenteacher.com or call 888-804-1486.

Where Do You Stand?

Where do you stand on the question of cutting back on fishing quotas? What is Mike's point of view? What is Ramon's point of view? With whom do you agree? Why do you think and feel the way you do about this issue?

Some of the factors that affect your decisions regarding an issue such as this one may include your familiarity with the fishing industry, your own likes and dislikes regarding fishing as a sport and as an industry, your reactions to fishing quotas being imposed in natural areas, and so on.

Can this issue be resolved? Can a compromise be found? Who will determine whether Mike's viewpoint or Ramon's viewpoint will be of more importance?

These are important questions that must be considered when complex environmental issues like this one occur. Decisions must be made.

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2. Wolves and Cattle*

   Wolves are natural inhabitants of Yellowstone National Park in Montana and Wyoming, but humans killed off all the wolves in the region in the early 1900s. After many years of work, environmental groups convinced the US government to release a pack of wolves in the park in order to re-establish a wolf population in the area.

   Sarah works for Wolves in the Wild. She says that wolves must return to these wild areas because they are an important part of the ecosystem and will help restore the natural population balance of many wildlife species. "We destroyed these animals in what was their natural habitat. It's only right that we return it to them. It isn't the same country without the wolves."

   Pete is a rancher. He points out that wolves don't know about park boundaries, and says there's no way to protect his cattle from them. "They're as happy to bring down a heifer as they are to kill a deer," claims Pete, "and I shouldn't have to have my cattle's lives threatened. This is now, not 75 years ago. The wolves are gone. Let them stay away. I have to make a living."

   Where do you stand on the question of introducing wolves back into the park?

(continued)

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* Source: Greene, Alanda. "Where Do You Stand?" *Green Teacher 54* (Winter 1997–98): 19–21. Adapted with permission. For information about this non-profit Canadian magazine, visit www.greenteacher.com or call 888-804-1486.

Note: In 1995 and 1996 wolves were captured from Canada and released in Yellowstone National Park. An additional 10 were moved from northern Montana into the park in 1997. Tracking and scat analysis has shown that concerns over cattle predation by wolves have not materialized.

For more information on the Yellowstone Wolf Project, visit the following website:

U.S. National Park Service. "Wolves of Yellowstone." *Yellowstone National Park*. www.nps.gov/yell/naturescience/wolves.htm.

Where Do You Stand?

Where do you stand on the question of reintroducing wolves into land that is also used for cattle? What is Sarah's point of view? What is Pete's point of view? With whom do you agree? Why do you think and feel the way you do about this issue?

As in the previous example, your stand on this issue depends on your life experience and value system. It depends on how you and your family make a living, what recreational activities you enjoy most, and whether or not you value the existence of wild species if they are dangerous to humans or their property.

This is another complicated issue that requires resolution. Who will decide whether Sarah or Pete (or neither) will be satisfied? Again, decisions must be made.

Learning Activity 5.4: Environmental Issues Affecting Manitoba

This learning activity lists and briefly describes 10 environmental issues affecting Manitoba. Consider each of the issues, read each brief summary, and then choose the one issue that you are interested in and would like to find out more about. You may want to do a little of your own research on a few issues before you make your final choice. Be sure to choose an issue that you are genuinely interested in and would enjoy researching. The issue you choose will be the subject of your research paper in the assignment for this lesson.

State the issue from the following list that you have chosen to learn more about.

Issue:

_____

Environmental Issues Affecting Manitoba

1. The Stability of Polar Bear Populations in Manitoba

It is estimated that about 1500 polar bears currently live in the western section of the Hudson Bay area, which extends from the Ontario border to the Northwest Territories. Over the last decade, polar bear numbers have steadily declined. Polar bear health has worsened as well. Fall weight of all age groups for both sexes has declined steadily, as has the reproductive rate of female bears. Environment Canada continues to conduct research aimed at understanding reasons for these recent trends. It has been postulated that climatic change due to global warming may be an important piece of the puzzle. From November to July, most bears spend much of their time on the sea ice of Hudson Bay. Pregnant females stay in dens on land from November to March, after which they take their cubs out onto the ice. Sea ice is not as abundant as it once was, and polar bears are being forced to spend more of the year on land. The greatest number of bears are forced onto coastal lands between the Nelson River and the town of Churchill. This reality means that bears are more often near human communities, a situation that can result in potentially dangerous contact. Manitoba does not have a commercial or recreational season for hunting polar bears; however, if bears pose a threat to human safety, they are occasionally shot. Orphaned cubs are made available to zoos if they meet strict specifications.

(continued)

Learning Activity 5.4: Environmental Issues Affecting Manitoba (continued)

2. Logging in Northern Manitoba and Its Impact on the Boreal Forest Ecosystem

The boreal forest of Canada covers a huge area that spans east to west from northern Newfoundland and Labrador to northern British Columbia and the Yukon. The Canadian boreal forest is actually part of a huge boreal forest ecosystem that includes areas of Russia, Japan, Scandinavia, and Alaska. The dominant tree species in the Canadian boreal forest are the black spruce and the jack pine. Over 90 percent of Canada's boreal forest is actually Crown land. Some of these lands are protected either provincially or nationally, but most have been designated as available for resource extraction, primarily for forestry, mining, and oil and gas extraction. In particular, logging has had a dramatic effect on many areas of the boreal forest in Canada. Management practices are not always aimed at long-term use and conservation but are, instead, driven by short-term profit. This is especially true in the southern band of boreal forests in Canada. One wild species that has been especially threatened by unwise logging practices is the woodland boreal caribou.

3. Pollution and Eutrophication of Lake Winnipeg

Lake Winnipeg is the tenth largest lake in the world. In recent years, Lake Winnipeg has shown signs of eutrophication, an increase in nutrient enrichment that causes huge algae blooms. These large mats of algae consume huge amounts of oxygen when they decompose. This decreased level of dissolved oxygen in the water can lead to fish kills and even to the loss of species. Some algae produce toxins that are dangerous to humans and other animals. The watershed of Lake Winnipeg is the second largest watershed in the world; it consists of four provinces and two states. Lake Winnipeg's watershed is about 40 times as large as the lake itself. About half the Canadian portion of the watershed is agricultural land; runoff from this land often contains fertilizers, pesticides, and animal waste. Human activities have resulted in a decrease in wetland ecosystems, which are nature's filtering systems. Without wetland environments to slow down the movement of nutrients into lakes, eutrophication can result. Flooding causes an increase in the speed of nutrient transport into lake ecosystems. The Red River empties into Lake Winnipeg, and the flooding that has occurred during the last several years has caused an increase in the nutrient content of the lake itself.

(continued)

Learning Activity 5.4: Environmental Issues Affecting Manitoba (continued)

4. The Presence of Introduced Species Such as the Zebra Mussel in Manitoba

The zebra mussel is a species that was introduced to the North American Great Lakes in 1985. These mussels were accidentally introduced by commercial shipping. The damage that zebra mussels have caused is dramatic and far-reaching. For example, waterworks facilities have become infested with zebra mussels, causing reduced water generation due to the clogging of pipes. Some municipalities have experienced poorer water quality because of compounds present in the water when zebra mussels are present in abundance. Zebra mussels clog water pipes, boat motors, irrigation lines, and cottage water intakes. The presence of zebra mussels has caused the decline of native mussel species and a marked decrease in the populations of some native fish. Zebra mussels feed on algae and prefer non-toxic species of algae. As a result, an increase in the number of zebra mussels has caused an increase in toxic species of algae. Toxic algae blooms have caused reductions in the numbers of other species, such as gulls, loons, and mergansers. Some of these toxins also affect people and have led to beach closures.

5. The Presence of Introduced Species Such as Purple Loosestrife in Manitoba

Purple loosestrife was introduced into North America from Europe in the early 1800s. This introduced species has caused many problems in natural ecosystems in Manitoba. It is a wetland plant species that is not eaten by any native bird, fish, or mammal. In Europe, there are about 120 species of insects that prey on loosestrife and keep its population in check. In North America, there are no natural predators or diseases to control its spread. Muskrats, for example, eat cattails but not loosestrife. Waterfowl species do not eat loosestrife seeds. Purple loosestrife germinates and grows very quickly; it forms dense, bush-like strands that are very difficult to eradicate. Purple loosestrife is an aggressive species that forces out native plant species. It can cause the stagnation of water in irrigation and drainage ditches. It can affect crop yields and reduce land resale values. Efforts to eradicate this invasive species have been largely unsuccessful. Burning does not generate enough heat to destroy the roots below the soil. Mowing or cutting creates pieces that can re-sprout by vegetative reproduction; it also does not destroy the roots. Even herbicide application does not destroy the seeds.

(continued)

6. The Conservation of At-Risk Species Such as the Burrowing Owl in Manitoba

The burrowing owl is an endangered grassland bird both in Manitoba and nationally. This species nests underground, using burrows that have been abandoned by ground squirrels, badgers, or foxes. Burrowing owls eat mostly insects but will also consume mice and small birds. These owls prefer short-grass pastures and prairies. Nests have even been found in ditches, croplands, and golf courses. Nesting owl pairs can be found in isolation or in loose colonies. Historically, burrowing owls were found in southern Manitoba, north to Dauphin and the Interlake and east to Winnipeg. Today, these owls are generally found only in the extreme southwestern corner of the province. In recent years, it is estimated that as few as 10 breeding pairs of burrowing owls live in Manitoba. Hundreds of breeding pairs probably lived in this province in the early to mid-1900s. Habitat loss is an important factor contributing to this decline. Agricultural expansion and urban expansion are largely to blame. Badgers, ground squirrels, and foxes are often seen as pests and, therefore, are not as numerous as they once were; burrows, therefore, are less abundant for burrowing owls to find and use. A decrease in prey abundance due to agricultural pest control measures may also be a contributing factor in the decline of this species of owl in Manitoba.

7. The Conservation of At-Risk Species Such as Lake Sturgeon in Manitoba

The lake sturgeon can live for up to 150 years and can be 2 metres or more in length. It is the largest freshwater fish species in Canada. Lake sturgeon do not reach sexual maturity until they are 20 to 30 years old, and spawn only every three to six years. Lake sturgeon were once very abundant in Manitoba rivers and large lakes; however, commercial fishing in the late 1800s and early 1900s greatly reduced their populations. Sturgeon populations in Manitoba have been seriously depleted by practices that include overfishing and the construction of dams. Habitat loss and degradation have further complicated the situation. Some sturgeon-stocking programs have been initiated in several areas in Manitoba.

(continued)

Learning Activity 5.4: Environmental Issues Affecting Manitoba (continued)

8. The Conservation of At-Risk Species Such as Woodland Caribou in Manitoba

As of 2006, the boreal woodland caribou has been listed as a threatened species in Manitoba. Boreal woodland caribou were at one time found throughout Manitoba's boreal forest. Since 1950, boreal woodland caribou numbers have decreased in Manitoba by about 50 percent. They have totally disappeared from the southern parts of the range they historically inhabited. The decline in this species has been caused by a variety of factors, including habitat loss largely due to logging, increased predation, parasites, diseases, and uncontrolled hunting. Habitats have also been severely affected by wildfires in the boreal forests of Manitoba. It is believed that between about 2000 and 3000 boreal woodland caribou now live in Manitoba.

9. The Use of Shelterbelts in Agricultural Areas of Manitoba

The province of Manitoba has funded farm shelterbelt planting programs to fight erosion since the 1930s. It is estimated that about 1300 kilometres of shelterbelts have been planted each year for the last several years. A shelterbelt is a wind barrier made of trees or shrubs. Field shelterbelts are planted to reduce wind erosion in agricultural fields. Fields where soil erosion is high are less productive and require greater inputs for adequate crop production. Shelterbelts can help increase the moisture in the soil available for crop growth because they trap snow during the winter. Because shelterbelts block the wind, moisture loss from the soil due to evaporation is also reduced. Wind damage to crops is also less of an issue when shelterbelts are used. Shelterbelts in agricultural areas provide important wildlife habitat and shelter, as well as corridors along which wildlife species can travel from one area to another. It has been estimated that a shelterbelt provides significant reduction in wind speed for a distance downwind equal to about 20 times the height of the shelterbelt itself.

(continued)

Learning Activity 5.4: Environmental Issues Affecting Manitoba (continued)

10. The Construction of Additional Hydroelectric Dams in Manitoba

In 1999, Manitoba Hydro, a Crown-owned utility, became the primary supplier of natural gas in Manitoba. In 2002, Manitoba Hydro was responsible for the generation and transmission of all hydroelectricity in the province. About 98 percent of the electricity that Manitoba Hydro generates is produced by 14 hydroelectric generating stations on rivers in the province.

Further generating stations/projects were being planned or were in progress at the time this course was developed:

- **Keeyask Generating Station:** Manitoba Hydro is planning to construct the Keeyask Generating Station on the Nelson River in the Split Lake Management Area about 725 kilometres northeast of Winnipeg. The Keeyask station will require the flooding of a substantial amount of habitat. Construction of the Keeyask station is not guaranteed at this time.
- **Conawapa Generating Station:** Manitoba Hydro is also planning the construction of the Conawapa Generating Station on the Lower Nelson River, about 28 kilometres downstream of the Limestone Generating Station. It would be the largest hydroelectric project ever undertaken in northern Manitoba. Conawapa would involve very little flooding of habitat; the land included in the area to be flooded lies almost entirely within the present natural banks of the Nelson River. No definite plans for when this project will be undertaken have been made at this time.
- **Wuskwatim Generation Project:** This project involves the building of a station at Taskinigup Falls on the Burntwood River in the Nelson House Resource Management Area, approximately 45 kilometres southwest of Thompson. This project is being developed as an equity partnership between the Nisichawayasihk Cree Nation and Manitoba Hydro. It would require less than half a square kilometre of flooding.

When you have completed this learning activity, check the Learning Activity Answer Key found at the end of this module. Remember that you do not need to submit learning activities to the Distance Learning Unit.

It is now time to do Assignment 5.4, researching and writing a paper on the issue you chose from Learning Activity 5.4. The assignment details can be found after the Lesson Summary.

Lesson Summary

In Lesson 4 of Module 5, you have learned about a number of important environmental issues affecting Manitoba. You have chosen one particular issue that interests you and have gathered information about it in writing your final research paper.

The final lesson in this course suggests some strategies you can use to study for the final examination you will write when you have finished Module 5 of this course. It also explains the examination format. You will learn what types of questions will appear on the final examination and what material will be assessed. Remember, your mark on the final examination determines 20 percent of your final mark in this course.

Notes

Assignment 5.4: An Environmental Issue in Manitoba (Research Paper) (35 marks)

Remember that you will submit this assignment to the Distance Learning Unit for assessment at the end of this module, along with the other assignments from Module 5.

In the learning activity for this lesson, you read about 10 environmental issues affecting Manitoba, and then chose one issue about which you would like to find out more. This assignment consists of writing a research paper on the particular environmental issue that you chose.

Keep in mind that this research paper is to be your original work. Do not copy text directly from any source unless you cite it in your paper. Do not plagiarize someone else's work.

Research Paper Guidelines and Assessment Criteria

The guidelines for writing your research paper are outlined below, followed by a chart identifying the criteria that will be used to assess your paper.

Length

Your paper should be at least three double-spaced, typewritten pages, in a font no larger than 12 point. If you choose to handwrite your paper, it should be of a similar length and following a similar format.

Components

Include the following sections in your paper:

- **Cover sheet:** This sheet should include the title of your paper, your name, and the date.
- **Topic:** Write a clear statement that names the environmental issue in Manitoba that you have chosen. The issue must be chosen from the list given in Learning Activity 5.4, which preceded this assignment.
- **Content:** Explain why the environmental issue you have chosen is a concern in Manitoba. Consider events and perspectives in the past that have led to the current issue you are investigating. Also consider various viewpoints on this issue, including arguments (positions) that oppose (differ from) yours.
- **Personal stand:** Having investigated the issue and having considered different points of view regarding it, state your personal viewpoint and explain your rationale for having it.

(continued)

Assignment 5.4: An Environmental Issue in Manitoba (Research Paper) (continued)

- **Future implications:** Conclude your paper with a statement of what you think the future will hold with respect to the issue you have chosen. Explain your reasons for making the predictions that you've made.

References

Include a list of references at the end of your paper. You should use at least three different sources, of which at least two must be sources other than encyclopedias (online or otherwise). Cite your sources using the style illustrated in the following **sample** citations (these samples are providd only as a style guide):

- **Books**

  Thames, Robert Patrick. *Biodiversity in the Tropics*. Louisville, ON: Macmillan, 1997.

- **Periodical Articles**

  Berridge, Mary. "The Molecular Basis of Life in the Cell." S*cientific American* (Nov. 2001): 57–75.

- **Websites**

  Kuyt, E. "Whooping Crane." Rev. 1993. *Hinterland Who's Who*. Canadian Wildlife Service and Canadian Wildlife Federation. 2003. http://www.hww.ca/hww2p.asp?id=79&cid=7 (7 July 2011).

  The Manitoba Museum. "Earth History Gallery." *Museum*. http://www.manitobamuseum.ca/main/museum/earth-history-gallery/ (7 July 2011).

Note: For websites, provide as much detail as you can find. Make sure you cite the full website address and the date you accessed it.

Assessment

The criteria that the Distance Learning Unit will use to assess your research paper are identified in the following chart.

(continued)

Assignment 5.4: An Environmental Issue in Manitoba (Research Paper) (continued)

Assessment Criteria		
Criteria		Marks
Length	Paper may be typed or handwritten. ■ Typed: At least three double-spaced typewritten pages, in a font no larger than 12 point. ■ Handwritten: Of a similar length and format.	*5 marks*
Cover sheet	■ Includes the title of the paper, the student's name, and the date.	*1 mark*
Topic	■ Gives a clear statement of the environmental issue selected (must be one of the issues identified in Learning Activity 5.4).	*2 marks*
Content	■ Provides a clear explanation of why the issue is important in Manitoba. ■ Considers events and perspectives from the past that contributed to the current importance of the issue. ■ **Explains different viewpoints on the issue.**	*12 marks*
Personal stand	■ States personal viewpoint on the issue. ■ Includes a rationale for the viewpoint taken.	*5 marks*
Future implications	■ States what the future may hold with respect to the issue. ■ Gives reasons for the prediction.	*5 marks*
References	■ Includes at least three different sources, at least two of which are sources other than encyclopedias. ■ Follows the specified reference style.	*5 marks*
	Total	***35 marks***

Notes

Module 5 Summary

Congratulations! You have almost finished the final module of this course. The last lesson in Module 5 will help you to prepare for your final examination.

Submitting Your Assignments

It is now time for you to submit your assignments from Module 5 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 5 assignments and organize your material in the following order:

- ❑ Cover Sheet for Module 5 (found at the end of the course Introduction)
- ❑ Assignment 5.1: Viewpoints on Maintaining Biodiversity
- ❑ Assignment 5.2: Sustainability of the Boreal Forest
- ❑ Assignment 5.3: Mark and Recapture Sampling
- ❑ Assignment 5.4: An Environmental Issue in Manitoba (Research Paper)

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

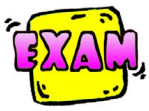
Notes

Lesson 5: Final Examination Review

Lesson Focus

This lesson does not address any specific learning outcomes.

Introduction



At the end of Module 2 of this course, you wrote a midterm examination, which was based on Modules 1 and 2. When you have completed Module 5, you will write the final examination, which is based on Modules 3, 4, and 5. The midterm and final examinations are each worth 20 percent of the final course mark, for a total of 40 percent.

This lesson suggests some strategies you can use to study for the final examination. It also explains the examination format. You will learn what types of questions will appear on the final examination and what material will be assessed. Remember, your mark on the final examination determines 20 percent of your final course mark.

Requesting Your Examination

At the end of this lesson, you will write your final examination. If you have not yet made arrangements to write it, then do so now. The instructions are provided in the course Introduction.

Study Strategies

In preparing for the final examination, use the following study strategies:

- **Review all learning activities and assignments:** Revisit the work you completed in Modules 3, 4, and 5. You could answer the questions in those exercises again, and then compare your answers with your original responses, with the Learning Activity Answer Key provided at the end of each module, and with your tutor/marker's assessment of your completed assignments.

- **Review vocabulary:** A review of vocabulary terms is also an effective way to review concepts. You could practise defining terms from Modules 3 to 5, perhaps by using index cards (using one side for a term and the other side for its definition). Keep in mind that one section of the examination asks you to connect pairs of terms by explaining how they are related, so try to connect vocabulary terms to one another as you study their definitions.
- **Review the names and contributions of scientists:** The work of many scientists was presented and discussed in Modules 3 to 5. As you prepare for the final examination, you could list the names of those scientists and then review the work that each person did. In doing so, you will study how the work of various scientists is related and has continued to add to current understanding of the biological world.
- **Review major concepts:** The sample questions that follow will give you some idea of the major concepts that may be addressed in the long-answer section of the final examination. As you study, you could outline an answer that explains each major concept. You will already have studied many of these concepts when you reviewed the learning activities and assignments from Modules 3 to 5 and when you studied the vocabulary from those three modules.

Examination Format

The final examination consists of the following five types of questions, the values of which combine to a total of 100 marks.

True or False ***(25 marks)***
In this section of the examination, you will decide whether each of the 25 statements is true or false, and you will indicate your choice by printing either T or F in the space provided for each statement.

Multiple Choice ***(15 marks)***
In this section, you will choose the single best answer to each of the questions given.

Matching ***(15 marks)***
In this section, you will match a list of 15 terms with their corresponding definitions. Each definition will be used only once.

Definitions and Connections ***(15 marks)***
In this section, you will choose five pairs of terms (out of seven pairs given). For each pair, you will define each term and then explain how the two terms are related.

Long Answer ***(30 marks)***
In this section, you will choose six long-answer questions (of the eight questions given). You will be asked to answer each selected question clearly and thoroughly in the space provided.

Sample Questions

Some sample examination questions are presented below. *Answers to the questions are provided in italic.*

True or False

1. Scientists believe that about 75 percent of all animal species on Earth today are insects.

   True

2. Charles Lyell proposed a theory of adaptation that included the inheritance of acquired traits.

   False – Jean Baptiste Lamarck was the scientist who made that proposal.

3. Halophiles are organisms that exist in extremely salty environments.

   True

4. A group of closely related species is called a genus.

   True

5. *Hyracotherium* is an extinct organism whose fossil remains indicate that it was related to the modern whale.

   False – It is believed to have been an ancestor of the modern horse.

Multiple Choice

1. Binomial nomenclature was introduced by
   a) Charles Darwin
   b) Julian Huxley
   c) Gregor Mendel
   d) Carolus Linnaeus

2. The five-kingdom system of classification in biology was first suggested by
   a) Gregor Mendel
   b) Robert Whittaker
   c) Charles Lyell
   d) Charles Darwin

3. All the combined ecosystems on Earth are considered to be one unit called
   a) the gene pool
   b) genetic drift
   c) the biosphere
   d) natural selection
4. The study of the evolutionary history of and relationships among various forms of life through time is
   a) ecology
   b) phylogenetics
   c) botany
   d) mammalogy
5. The phonetic approach to classification depends heavily on the study of
   a) eating habits
   b) ecological niches
   c) life history
   d) morphology

Matching

C	1. paleontology	A. Life forms that lack true nuclei.
B	2. *Archaeopteryx*	B. An ancient animal that possessed characteristics of modern reptiles and birds.
E	3. uniformitarianism	C. The study of fossil remains.
A	4. prokaryotic	D. A phenotypic characteristic of an organism that allows it to survive to reproduce more successfully than another organism.
D	5. adaptation	E. The idea that the natural processes we see occurring now have also occurred in the past.

Definitions and Connections

1. *prokaryotes* and *eukaryotes*
   - *Prokaryotes are organisms whose cells lack a true nucleus. Prokaryotic cells are more primitive life forms than eukaryotes.*
   - *Eukaryotes are organisms whose cells possess a true nucleus. All the more advanced life forms on Earth are eukaryotic.*
   - *Both terms apply to organisms and help us to classify them into groups in a meaningful way.*
2. *stabilizing selection* and *disruptive selection*
   - *Stabilizing selection favours individuals with an average value for a trait, and selects against those with extreme values.*
   - *Disruptive selection favours individuals at both ends of the distribution, and selects against the average.*
   - *Both are types of natural selection and are ways in which the traits seen in natural populations can change over time.*

Long Answer

A list of topics that could be addressed in long-answer questions on the final examination is given below. After you have reviewed your knowledge about each topic, you could refer to the course material to check for accuracy and completeness.

1. Current theories explaining human evolution and the forms of evidence that support those theories
2. The four strategies to conserve biodiversity and an explanation of each
3. The Hardy-Weinberg principle and how it is used in population genetics
4. The important contributions of scientists such as Charles Lyell, Charles Darwin, Jean Baptiste Lamarck, and Alfred Russell Wallace
5. The six important concepts that make up Darwin's theory of natural selection
6. The phenetic and cladistic approaches to classification of living things
7. Allopatric speciation and sympatric speciation
8. The five primary types of evidence that scientists use to classify organisms
9. The two primary approaches taken to explain the pace of evolutionary change: gradualism and punctuated equilibrium
10. The difference between preservation and conservation of natural resources

Summary

Good luck as you prepare for the final examination. If you have completed all the learning activities and assignments from Modules 3, 4, and 5, and have used the suggested strategies in studying for the examination, you have prepared yourself well. The final examination will provide an opportunity for you to show what you know.

Module 5 Summary

Congratulations! You have almost finished the final module of this course. The last lesson in Module 5 will help you to prepare for your final examination.

Submitting Your Assignments

It is now time for you to submit your assignments from Module 5 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 5 assignments and organize your material in the following order:

- ❑ Cover Sheet for Module 5 (found at the end of the course Introduction)
- ❑ Assignment 5.1: Viewpoints on Maintaining Biodiversity
- ❑ Assignment 5.2: Sustainability of the Boreal Forest
- ❑ Assignment 5.3: Mark and Recapture Sampling
- ❑ Assignment 5.4: An Environmental Issue in Manitoba (Research Paper)

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

Notes

Grade 12 Biology (40S)

Module 5
Conservation of Biodiversity

Learning Activity Answer Key

Module 5:
Conservation of Biodiversity

Learning Activity 5.1: The Value of Natural Resources

Each of the following natural resources is arguably of value to human beings. For each natural resource listed, you were asked to state whether you believed it to be primarily of utilitarian value, intrinsic value, or both. You explained your choice.

1. Apples

   Answers will vary, depending on individual perspectives.

   - **Utilitarian:** Apples can be consumed by human beings and also by some of the animals that are domesticated by human beings. They can be cultivated and sold. Many varieties of apples have been developed, increasing their economic value. They can be shipped over long distances.
   - **Intrinsic:** Apple trees are beautiful, especially in the spring. Growing and selling apples is a pleasurable experience for some. People enjoy eating apples, cooking them, smelling them, and seeing them.

2. Sunflowers

   Answers will vary.

   - **Utilitarian:** Sunflowers can be used for their seeds and oil, both of which are of economic value. Some birds eat sunflower seeds.
   - **Intrinsic:** A field of sunflowers is beautiful. Some people grow them in their yards.

3. Natural gas

   Answers will vary.

   - **Utilitarian:** Natural gas is used primarily as a fuel source for a variety of purposes, such as cooking, heating buildings, and powering various types of machinery.
   - **Intrinsic:** It could be argued that a natural gas fireplace, for example, provides enjoyment to some people.

4. Golden eagles

Answers will vary.

- **Utilitarian:** Drawings, paintings, and sculptures of golden eagles can be created and sold. The presence of golden eagles in a certain area may make it more appealing to some people and, therefore, increase the area's economic value.
- **Intrinsic:** Some people value the beauty or power of the golden eagle. It may represent freedom or the wilderness to some.

5. Lake Winnipeg

Answers will vary.

- **Utilitarian:** Lake Winnipeg provides recreational opportunities, such as swimming and sailing, for many people. It also provides commercial fisheries with their catch. Shipbuilders benefit from the lake's existence as well. Lakefront property is generally of higher value because of its location, although flooding may also be a problem at times.
- **Intrinsic:** Lake Winnipeg is immense and beautiful. It has existed for a long time and is rich in history. Some people value being able to see a sunrise over the lake or to sit on the beach.

Learning Activity 5.2: Conservation and Preservation

This learning activity helped you to review what you had learned about strategies to conserve and preserve biodiversity.

1. Clearly explain the difference between conservation and preservation, both of which involve actions taken to protect natural resources.

   The important distinction between these strategies is that conservation involves the wise use of natural resources, whereas preservation typically involves the non-use and protection of natural resources.

2. Provide an example of how conservation practices and preservation practices can be used in combination to protect natural resources effectively.

   You could name many examples. One example is the Canada goose. In Manitoba, this bird is a game animal. There is a hunting season for Canada geese, and hunters have to purchase licences to hunt them. The geese that live in areas designated as wildlife sanctuaries cannot be hunted. Habitats for geese are actively maintained and protected so that geese can successfully breed and survive in Manitoba. Keeping these geese as pets is not permitted.

3. Which approach to natural resource management is more effective, conservation or preservation?

   There is no easy answer to this question. A combination of both conservation and preservation during different times of the year and in different areas is very effective. Often, the protection of living species and the protection of natural habitats must be considered in combination. Decisions regarding the protection of natural resources require careful analysis of research and application of management tools and methods.

Learning Activity 5.3: Transect and Quadrat Sampling

In this two-part learning activity, you were provided with a list of materials and directions for using two methods of sampling population size: *transect sampling* and *quadrat sampling*. You recorded your results in data tables, and then used your results to analyze your investigation.

Part 1: Transect Sampling

In Part 1, you practised transect sampling, using the instructions provided. Specifically, you conducted five trials to estimate the number of letter *e*'s (small and capital) found along a transect line (a ruler dropped on randomly selected pages of a textbook), recording your findings for each trial in a data table.

Data Table	
Trial	Number of Letter *e*'s and *E*'s
1	Results will vary, based on individual trials.
2	
3	
4	
5	

Part 2: Quadrat Sampling

In Part 2, you practised quadrat sampling, using the instructions provided. Specifically, you conducted five trials to estimate the number of letter *e*'s (small and capital) found entirely or partially within a quadrat (an area covered by a square piece of cardboard tossed on randomly selected pages of a textbook), recording your findings for each trial in a data table.

Data Table	
Trial	Number of Letter *e*'s and *E*'s
1	Results will vary, based on individual trials.
2	
3	
4	
5	

Analysis

1. Calculate the average number of letter *e*'s (small and capital combined) on a page of your textbook.

   a) Using the transect method:

   Answers will vary.

   b) Using the quadrat method:

   Answers will vary.

2. Calculate the average number of letter *e*'s (small and capital combined) in your textbook by multiplying the average number of *e*'s per page by the number of pages in the textbook.

   a) Using the transect method:

   Answers will vary.

   b) Using the quadrat method:

   Answers will vary.

3. Compare the transect method estimate and the quadrat method estimate of the number of *e*'s (small and capital) in your textbook. Why might the two estimates differ?

   A number of reasons could explain a difference if it exists. Each method was used only five times. You would probably find that the difference between the two methods would decrease if each method were used a higher number of times. It is possible that not all 10 trials were conducted randomly. Perhaps, for example, it was more likely for the ruler to fall in the centre of the page than for the cover slip or cardboard to fall in the centre. Also, perhaps the length of the transect line was not comparable to the size of the quadrat used.

Learning Activity 5.4: Environmental Issues Affecting Manitoba

In this learning activity, you read brief summaries of the following 10 environmental issues affecting Manitoba. You then chose one issue, from the 10 issues described, as the subject of your research paper in Assignment 5.4.

Environmental Issues Affecting Manitoba

1. The Stability of Polar Bear Populations in Manitoba
2. Logging in Northern Manitoba and Its Impact on the Boreal Forest Ecosystem
3. Pollution and Eutrophication of Lake Winnipeg
4. The Presence of Introduced Species Such as the Zebra Mussel in Manitoba
5. The Presence of Introduced Species Such as Purple Loosestrife in Manitoba
6. The Conservation of At-Risk Species Such as the Burrowing Owl in Manitoba
7. The Conservation of At-Risk Species Such as Lake Sturgeon in Manitoba
8. The Conservation of At-Risk Species Such as Woodland Caribou in Manitoba
9. The Use of Shelterbelts in Agricultural Areas of Manitoba
10. The Construction of Additional Hydroelectric Dams in Manitoba

State the issue from the above list that you chose to learn more about.

Issue:

Answers will vary. One of the 10 issues listed should be restated here and will be focused on in the following assignment.

Biology Videos

Module 5

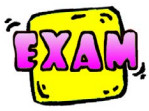
1. Video - Why is biodiversity so important? - Kim Preshoff
    a. Our planet's diverse, thriving ecosystems may seem like permanent fixtures, but they're actually vulnerable to collapse. Jungles can become deserts, and reefs can become lifeless rocks. What makes one ecosystem strong and another weak in the face of change? Kim Preshoff details why the answer, to a large extent, is biodiversity. Lesson by Kim Preshoff, animation by TED-Ed.
2. Video - How biodiversity is maintained and why is important for ecosystem functioning?
3. Video - Reasons for Maintaining Biodiversity | A-level Biology | OCR, AQA, Edexcel
4. Video - Conservation and Restoration Ecology: Crash Course Ecology #12
5. Video - Learning to protect biodiversity
6. Video - Biodiversity Conservation
7. Video - Sustainable Forestry
8. Video - Measuring Biodiversity (Extra)
9. Video - Mark recapture population estimation
10. Video - Mark-release-recapture.mp4

Lesson 5: Final Examination Review

Lesson Focus

This lesson does not address any specific learning outcomes.

Introduction



At the end of Module 2 of this course, you wrote a midterm examination, which was based on Modules 1 and 2. When you have completed Module 5, you will write the final examination, which is based on Modules 3, 4, and 5. The midterm and final examinations are each worth 20 percent of the final course mark, for a total of 40 percent.

This lesson suggests some strategies you can use to study for the final examination. It also explains the examination format. You will learn what types of questions will appear on the final examination and what material will be assessed. Remember, your mark on the final examination determines 20 percent of your final course mark.

Requesting Your Examination

At the end of this lesson, you will write your final examination. If you have not yet made arrangements to write it, then do so now. The instructions are provided in the course Introduction.

Study Strategies

In preparing for the final examination, use the following study strategies:

- **Review all learning activities and assignments:** Revisit the work you completed in Modules 3, 4, and 5. You could answer the questions in those exercises again, and then compare your answers with your original responses, with the Learning Activity Answer Key provided at the end of each module, and with your tutor/marker's assessment of your completed assignments.

- **Review vocabulary:** A review of vocabulary terms is also an effective way to review concepts. You could practise defining terms from Modules 3 to 5, perhaps by using index cards (using one side for a term and the other side for its definition). Keep in mind that one section of the examination asks you to connect pairs of terms by explaining how they are related, so try to connect vocabulary terms to one another as you study their definitions.
- **Review the names and contributions of scientists:** The work of many scientists was presented and discussed in Modules 3 to 5. As you prepare for the final examination, you could list the names of those scientists and then review the work that each person did. In doing so, you will study how the work of various scientists is related and has continued to add to current understanding of the biological world.
- **Review major concepts:** The sample questions that follow will give you some idea of the major concepts that may be addressed in the long-answer section of the final examination. As you study, you could outline an answer that explains each major concept. You will already have studied many of these concepts when you reviewed the learning activities and assignments from Modules 3 to 5 and when you studied the vocabulary from those three modules.

Examination Format

The final examination consists of the following five types of questions, the values of which combine to a total of 100 marks.

True or False ***(25 marks)***
In this section of the examination, you will decide whether each of the 25 statements is true or false, and you will indicate your choice by printing either T or F in the space provided for each statement.

Multiple Choice ***(15 marks)***
In this section, you will choose the single best answer to each of the questions given.

Matching ***(15 marks)***
In this section, you will match a list of 15 terms with their corresponding definitions. Each definition will be used only once.

Definitions and Connections ***(15 marks)***
In this section, you will choose five pairs of terms (out of seven pairs given). For each pair, you will define each term and then explain how the two terms are related.

Long Answer ***(30 marks)***
In this section, you will choose six long-answer questions (of the eight questions given). You will be asked to answer each selected question clearly and thoroughly in the space provided.

Sample Questions

Some sample examination questions are presented below. *Answers to the questions are provided in italic.*

True or False

1. Scientists believe that about 75 percent of all animal species on Earth today are insects.

   True

2. Charles Lyell proposed a theory of adaptation that included the inheritance of acquired traits.

   False – Jean Baptiste Lamarck was the scientist who made that proposal.

3. Halophiles are organisms that exist in extremely salty environments.

   True

4. A group of closely related species is called a genus.

   True

5. *Hyracotherium* is an extinct organism whose fossil remains indicate that it was related to the modern whale.

   False – It is believed to have been an ancestor of the modern horse.

Multiple Choice

1. Binomial nomenclature was introduced by
   a) Charles Darwin
   b) Julian Huxley
   c) Gregor Mendel
   d) Carolus Linnaeus

2. The five-kingdom system of classification in biology was first suggested by
   a) Gregor Mendel
   b) Robert Whittaker
   c) Charles Lyell
   d) Charles Darwin

3. All the combined ecosystems on Earth are considered to be one unit called
   a) the gene pool
   b) genetic drift
   c) the biosphere
   d) natural selection
4. The study of the evolutionary history of and relationships among various forms of life through time is
   a) ecology
   b) phylogenetics
   c) botany
   d) mammalogy
5. The phonetic approach to classification depends heavily on the study of
   a) eating habits
   b) ecological niches
   c) life history
   d) morphology

Matching

C	1. paleontology	A. Life forms that lack true nuclei.
B	2. *Archaeopteryx*	B. An ancient animal that possessed characteristics of modern reptiles and birds.
E	3. uniformitarianism	C. The study of fossil remains.
A	4. prokaryotic	D. A phenotypic characteristic of an organism that allows it to survive to reproduce more successfully than another organism.
D	5. adaptation	E. The idea that the natural processes we see occurring now have also occurred in the past.

Definitions and Connections

1. *prokaryotes* and *eukaryotes*
   - *Prokaryotes are organisms whose cells lack a true nucleus. Prokaryotic cells are more primitive life forms than eukaryotes.*
   - *Eukaryotes are organisms whose cells possess a true nucleus. All the more advanced life forms on Earth are eukaryotic.*
   - *Both terms apply to organisms and help us to classify them into groups in a meaningful way.*
2. *stabilizing selection* and *disruptive selection*
   - *Stabilizing selection favours individuals with an average value for a trait, and selects against those with extreme values.*
   - *Disruptive selection favours individuals at both ends of the distribution, and selects against the average.*
   - *Both are types of natural selection and are ways in which the traits seen in natural populations can change over time.*

Long Answer

A list of topics that could be addressed in long-answer questions on the final examination is given below. After you have reviewed your knowledge about each topic, you could refer to the course material to check for accuracy and completeness.

1. Current theories explaining human evolution and the forms of evidence that support those theories
2. The four strategies to conserve biodiversity and an explanation of each
3. The Hardy-Weinberg principle and how it is used in population genetics
4. The important contributions of scientists such as Charles Lyell, Charles Darwin, Jean Baptiste Lamarck, and Alfred Russell Wallace
5. The six important concepts that make up Darwin's theory of natural selection
6. The phenetic and cladistic approaches to classification of living things
7. Allopatric speciation and sympatric speciation
8. The five primary types of evidence that scientists use to classify organisms
9. The two primary approaches taken to explain the pace of evolutionary change: gradualism and punctuated equilibrium
10. The difference between preservation and conservation of natural resources

Summary

Good luck as you prepare for the final examination. If you have completed all the learning activities and assignments from Modules 3, 4, and 5, and have used the suggested strategies in studying for the examination, you have prepared yourself well. The final examination will provide an opportunity for you to show what you know.

Grade 12 Biology (40S)

Appendix: Specific Learning Outcomes

Appendix: Specific Learning Outcomes

Module 1: Understanding Biological Inheritance

Lesson 1: Introduction to Genetics

B12-1-01 Outline Gregor Mendel's principles of inheritance, stating their importance to the understanding of heredity.

Include: principles of segregation, dominance, and independent assortment

B12-1-02 Explain what is meant by the terms *heterozygous* and *homozygous*.

B12-1-03 Distinguish between *genotype* and *phenotype*, and use these terms appropriately when discussing the outcomes of genetic crosses.

Lesson 2: Making Predictions in Genetics

B12-1-04 Use Punnett squares to solve a variety of autosomal inheritance problems, and justify the results using appropriate terminology.

Include: monohybrid cross, dihybrid cross, test cross, P generation, F_1 generation, F_2 generation, phenotypic ratio, genotypic ratio, dominant alleles, recessive alleles, purebred, hybrid, and carrier

B12-1-05 Describe examples of and solve problems involving the inheritance of phenotypic traits that do not follow a dominant-recessive pattern.

Examples: co-dominance, incomplete dominance, multiple alleles, lethal genes . . .

Lesson 3: Sex Determination and Sex-Linked Traits

B12-1-06 Explain the basis for sex determination in humans.

Include: XX and XY chromosomes

B12-1-07 Describe examples of and solve problems involving sex-linked genes.

Examples: red-green colour-blindness, hemophilia, Duchenne muscular dystrophy . . .

Lesson 4: Inheritance Patterns and the Ethics of Predicting Genetics

B12-1-08 Use pedigree charts to illustrate the inheritance of genetically determined traits in a family tree and to determine the probability of certain offspring having particular traits.

Include: symbols and notations used

B12-1-09 Discuss ethical issues that may arise as a result of genetic testing for inherited conditions or disorders.

Lesson 5: Genetic Mutations

B12-1-10 Discuss the role of meiosis and sexual reproduction in producing genetic variability in offspring.

Include: crossing over and randomness

B12-1-11 Explain how chromosome mutations may arise during meiosis.

Include: nondisjunction

B12-1-12 Identify monosomy and trisomy chromosome mutations from karyotypes.

Examples: Down syndrome, Turner syndrome, Klinefelter syndrome . . .

Module 2: Mechanisms of Inheritance

Lesson 1: The Discovery of DNA

B12-2-01 Outline significant scientific contributions/discoveries that led to the current understanding of the structure and function of the DNA molecule.

Include: timeline, individual contributions, multidisciplinary collaboration, and competitive environment

Lesson 2: The Structure of DNA

B12-2-02 Describe the structure of a DNA nucleotide.

Include: deoxyribose sugar, phosphate group, and nitrogenous bases

B12-2-03 Describe the structure of a DNA molecule.

Include: double helix, nucleotides, base pairing, and gene

Lesson 3: Replication, Transcription, and Translation

B12-2-04 Describe the process of DNA replication.

Include: template, semi-conservative replication, and role of enzymes

B12-2-05 Compare DNA and RNA in terms of their structure, use, and location in the cell.

B12-2-06 Outline the steps involved in protein synthesis.

Include: mRNA, codon, amino acid, transcription, tRNA, anticodon, ribosome, and translation

Lesson 4: Genetic Mutations

B12-2-07 Relate the consequences of gene mutation to the final protein product.

Examples: point mutation in sickle-cell anemia, frameshift mutation in β-thalassemia . . .

B12-2-08 Discuss implications of gene mutation for genetic variation.

Include: source of new alleles

Lesson 5: Applications of Genetic Knowledge

B12-2-09 Investigate an issue related to the application of gene technology in bioresources.

Include: understanding the technology/processes involved, economic implications, a variety of perspectives, and personal/societal/global implications

B12-2-10 Investigate an issue related to the application of gene technology in humans.

Include: understanding the technology/processes involved, ethical and legal implications, a variety of perspectives, and personal/societal/global implications

Module 3: Evolutionary Theory and Biodiversity

Lesson 1: Science and Evolution

B12-3-01 Define the term *evolution*, explaining how evolution has led to biodiversity by altering populations and not individuals.

Include: gene pool and genome

Lesson 2: Darwin's Theory of Natural Selection

B12-3-02 Describe and explain the process of discovery that led Charles Darwin to formulate his theory of evolution by natural selection.

Include: the voyage of the *Beagle*, Darwin's observations of South American fossils, the impact of the Galapagos Islands on his thinking, and the work of other scientists

B12-3-03 Outline the main points of Darwin's theory of evolution by natural selection.

Include: overproduction, competition, variation, adaptation, natural selection, and speciation

B12-3-04 Demonstrate, through examples, what the term *fittest* means in the phrase "survival of the fittest."

Examples: stick insects blending with their environment, sunflowers bending toward sunlight, antibiotic-resistant bacteria . . .

Lesson 3: Adaptation

B12-3-05 Explain how natural selection leads to changes in populations.

Examples: industrial melanism, antibiotic-resistant bacteria, pesticide-resistant insects . . .

B12-3-06 Describe how disruptive, stabilizing, and directional natural selection act on variation.

B12-3-07 Distinguish between *natural selection* and *artificial selection*.

Lesson 4: Population Genetics

B12-3-08 Outline how scientists determine whether a gene pool has changed, according to the criteria for genetic equilibrium.

Include: large population, random mating, no gene flow, no mutation, and no natural selection

B12-3-09 Discuss how genetic variation in a gene pool can be altered.

Examples: natural selection, gene flow, genetic drift, non-random mating, mutation . . .

Lesson 5: Evolution and Speciation

B12-3-10 Describe how populations can become reproductively isolated.

Examples: geographic isolation, niche differentiation, altered behaviour, altered physiology. . .

B12-3-11 With the use of examples, differentiate between *convergent evolution* and *divergent evolution* (adaptive radiation).

B12-3-12 Distinguish between the two models for the pace of evolutionary change: punctuated equilibrium and gradualism.

Module 4: Organizing Biodiversity

Lesson 1: Defining Biodiversity

B12-4-01 Define the concept of biodiversity in terms of ecosystem, species, and genetic diversity.

Lesson 2: Defining a Species

B12-4-02 Explain why it is difficult to determine a definition of species.

Examples: hybrids such as mules, phenotypic variations in a species, non-interbreeding subpopulations . . .

Lesson 3: Systems of Classification

B12-4-03 Describe the dynamic nature of classification.

Include: different systems and current debates

B12-4-04 Describe types of evidence used to classify organisms and determine evolutionary relationships.

Examples: fossil record, DNA analysis, biochemistry, embryology, morphology . . .

Lesson 4: The Three Domains of Life

B12-4-05 Compare the characteristics of the domains of life.

Include: Archaea (Archaebacteria), Bacteria (Eubacteria), and Eukarya

B12-4-06 Compare the characteristics of the kingdoms in the Eukarya domain.

Include: cell structure, major mode of nutrition, cell number, and motility

Lesson 5: Evolutionary Trends

B12-4-07 Investigate an evolutionary trend in a group of organisms.

Examples: hominid evolution, vascularization in plants, animal adaptations for life on land . . .

Module 5: Conservation of Biodiversity

Lesson 1: Maintaining Biodiversity

B12-5-01 Discuss a variety of reasons for maintaining biodiversity.

Include: maintaining a diverse gene pool, economic value, and sustainability of an ecosystem

Lesson 2: Strategies to Conserve Biodiversity

B12-5-02 Describe strategies used to conserve biodiversity.

Examples: habitat preservation, wildlife corridors, species preservation programs, public education . . .

Lesson 3: Methods of Monitoring Biodiversity

B12-5-03 Select and use appropriate tools or procedures to determine and monitor biodiversity in an area.

Examples: field guides, dichotomous keys, quadrats, transects, mark and recapture . . .

Lesson 4: Issues in Conservation

B12-5-04 Investigate an issue related to the conservation of biodiversity.

Examples: heritage seeds, water quality in Lake Winnipeg, land-use designations, hydroelectric development . . .

Grade 12 Biology (40S)

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All Supporting Videos for Grade 11 Biology

Module 1

1. Gregor Mendel and the Principles of Inheritance
2. Video - Gregor Mendel's Principles of Inheritance
3. Video - Learn Biology: How to Draw a Punnett Square
    a. A Punnett square is used to predict the chances of an offspring to have its parents' traits. These squares are most commonly divided into four parts, with each part equalling a 25% chance of the offspring receiving that set of genes. More complicated squares may have more than four parts, though the same basic method applies. The letters surrounding and within each square represent alleles. They are one part of a gene pair occupying a specific part of a chromosome. All dominate alleles have capital letters, while the recessive ones are lowercase. Dominate alleles will always overpower recessive ones in the expression of the gene.
4. Video - Sex Chromosomes and Sex-Linked Traits
5. Video - Sex-Linked Traits
6. Ethical issues in predictive genetic testing: a public health perspective
7. Patterns of Inheritance
8. Genetic Testing FAQ
9. Pedigree Analysis in Human Genetics: Inheritance Patterns
10. What is a gene mutation and how do mutations occur?
11. An introduction to genetic mutations
12. Video - DNA Mutations | Genetics | Biology
13. Video - Mutations: The Potential Power of a Small Change
14. Video - Chromosomal Abnormalities and Non-Disjunction
15. Video - Chromosomes and Karyotypes

Module 2

1. Video - The Discovery of the Structure of DNA
2. Video - DNA Structure and Replication: Crash Course Biology #10
3. Video - DNA replication and RNA transcription and translation | Khan Academy
4. Video - DNA Replication: The Cell's Extreme Team Sport
5. Video - DNA Mutation 3D Animation
6. Video - An introduction to genetic mutations | Biomolecules | MCAT | Khan Academy
7. Video - Genetic Engineering in Agriculture: The Future of Food
8. Video - Biotechnology: Genetic Modification, Cloning, Stem Cells, and Beyond
9. Video - Designer Babies: The Science and Ethics of Genetic Engineering
10. Video - The Ethics of Human Gene Editing: Unnatural Selection

Module 3

1. Video - What is Evolution?
2. Video - Evolution: It's a Thing - Crash Course Biology #20
3. Video - Evidence for evolution | Biology | Khan Academy
4. The Making of a Theory: Darwin, Wallace, and Natural Selection
5. Video - DARWIN'S THEORIES
6. Video - Charles Darwin - The Theory Of Natural Selection
7. Video - What is SURVIVAL OF THE FITTEST? What does SURVIVAL OF THE FITTEST mean?
8. Video - Adaptation and Natural Selection
9. Video - Natural Selection
10. Video - Population Genetics: When Darwin Met Mendel - Crash Course Biology #18
11. Video - Population Genetics
12. Video - Genetic Drift
13. Video - Speciation
14. Video - Evolution and Speciation
15. Video - Speciation

Module 4

1. Video - What is Biodiversity & Its Importance? Environmental Science for Kids | Educational Videos by Mocomi
2. Video - Learn Biology: Biodiversity Definition

Module 5

1. Video - Why is biodiversity so important? - Kim Preshoff
    a. Our planet's diverse, thriving ecosystems may seem like permanent fixtures, but they're actually vulnerable to collapse. Jungles can become deserts, and reefs can become lifeless rocks. What makes one ecosystem strong and another weak in the face of change? Kim Preshoff details why the answer, to a large extent, is biodiversity. Lesson by Kim Preshoff, animation by TED-Ed.
2. Video - How biodiversity is maintained and why is important for ecosystem functioning?
3. Video - Reasons for Maintaining Biodiversity | A-level Biology | OCR, AQA, Edexcel
4. Video - Conservation and Restoration Ecology: Crash Course Ecology #12
5. Video - Learning to protect biodiversity
6. Video - Biodiversity Conservation
7. Video - Sustainable Forestry
8. Video - Measuring Biodiversity (Extra)
9. Video - Mark recapture population estimation
10. Video - Mark-release-recapture.mp4