This document is intended for

| Students | ✓ |
| Teachers (Biology 30) | ✓ |
| Administrators | |
| Parents | |
| General Public | |
| Other | |

Biology 30
Student Module
Module 5
Heredity and Molecular Genetics
Alberta Distance Learning Centre
ISBN 0-7741-0977-7

ALL RIGHTS RESERVED

Copyright © 1994, the Crown in Right of Alberta, as represented by the Minister of Education, Alberta Education, 11160 Jasper Avenue, Edmonton, Alberta, T5K 0L2. All rights reserved. Additional copies may be obtained from the Learning Resources Distributing Centre.

No part of this courseware may be reproduced in any form, including photocopying (unless otherwise indicated), without the written permission of Alberta Education.

Every effort has been made both to provide proper acknowledgement of the original source and to comply with copyright law. If cases are identified where this has not been done, please notify Alberta Education so appropriate corrective action can be taken.

IT IS STRICTLY PROHIBITED TO COPY ANY PART OF THESE MATERIALS UNDER THE TERMS OF A LICENCE FROM A COLLECTIVE OR A LICENSING BODY.
Welcome to Module 5

We hope you’ll enjoy your study of *Heredity and Molecular Genetics*. Remember, to make your learning a bit easier, several videocassettes and laser videodiscs are referred to throughout the modules. Your textbook, *Nelson Biology*, will enhance your studies.

Good Luck!
COURSE OVERVIEW

This course contains seven modules. The module you are working in is highlighted in a darker colour.

Biology 30

Module 1
The Nervous System

Module 2
Hormones and Control

Module 3
Reproduction and Human Development

Module 4
Cell Division and Classical Genetics

Module 5
Heredity and Molecular Genetics

Module 6
Population Dynamics

Module 7
Populations and Communities
Module Overview ............................................................... 1
   Evaluation ....................................................................... 2

Section 1: Genes and Chromosomes ................................ 3
   Activity 1: What's in Chromosomes? ............................ 4
   Activity 2: Mapping Chromosomes .............................. 5
   Follow-up Activities ...................................................... 9
      Extra Help ............................................................... 9
      Enrichment ................................................................ 11
   Conclusion .................................................................... 11
   Assignment .................................................................... 12

Section 2: The Molecules of Heredity .............................. 18
   Activity 1: Inside Genes ............................................... 19
   Activity 2: From Code to Trait ..................................... 22
   Follow-up Activities .................................................... 27
      Extra Help ............................................................. 28
      Enrichment ............................................................ 30
   Conclusion .................................................................... 30
   Assignment .................................................................... 31
Module 5 Contents

Section 3: Biochemical Technology

Activity 1: Mutation: An Error with a Purpose ............... 38
Activity 2: Genetic Engineering: Human Solutions ........ 44
Activity 3: Disease Research: Knowledge or Wisdom? ... 47
Follow-up Activities ......................................................... 48
   Extra Help ................................................................. 48
   Enrichment ............................................................... 50
Conclusion ................................................................. 50
Assignment .............................................................. 50

Module Summary .......................................................... 52

Appendix ........................................................................ 54
   Glossary .................................................................. 55
   Suggested Answers .................................................. 55
   DNA Symbols .......................................................... 79
MODULE OVERVIEW

Completing your education successfully is all that is needed to gain productive and meaningful employment, right? Well, maybe not. Suppose you had to take a physical examination. Can you imagine failing a physical examination for your first full-time job? Impossible, you say – you have been healthy all your life. Nevertheless, your doctor has discovered a genetic disorder that would put your health at risk if you were exposed to the conditions at the work site. Now what?

While it may sound far-fetched, science and technology have made careful genetic screening possible. They have also made engineering certain solutions possible. The mysteries inside the nucleus of every cell in your body are just beginning to be unravelled. Some of the most intriguing advances in medicine and agriculture are the result of the expanding knowledge of genetics and heredity.

In this module you’ll expand your knowledge of genetics as you study how genetic traits are carried in cells and transferred into actual characteristics. Using this knowledge you’ll be able to understand and appreciate how genetic engineering can decipher, correct, and even control this mechanism that controls life itself.
Evaluation

Your mark in this module will be determined by how well you complete the assignments at the end of each section. You must complete all assignments. In this module you are expected to complete three assignments. The mark distribution is as follows:

<table>
<thead>
<tr>
<th>Section 1 Assignment</th>
<th>40 marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 2 Assignment</td>
<td>40 marks</td>
</tr>
<tr>
<td>Section 3 Assignment</td>
<td>20 marks</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>100 marks</strong></td>
</tr>
</tbody>
</table>

When doing your assignments, work slowly and carefully. If you are having difficulties, go back and review the appropriate section.

Read all parts of your assignment carefully. Plan and do your rough work on your own paper. Revise and edit your responses; then set up your final copy for submission on your own paper. Lined looseleaf is recommended. Make sure your answers are neat and organized, with wide left margins and space for teacher comments after each assignment.

When you see this icon, ideas and details are provided to help you set up and organize your answer in a certain way.

Before submitting your responses, be sure to proofread them carefully to ensure they say what you want, that they are neat and clear, and that they are complete and missing no material.

You will be submitting only your assignment response pages for evaluation.

It is important to number and clearly identify each page with this information placed at the top.

Notice that for some assignment questions two marks are given for communication. This is indicated at the end of a question. For two marks your response should clearly and logically answer the question and show strong linkages between cause and effect. Your answer should consist of complete sentences and use appropriate scientific terminology. Diagrams may be an appropriate part of your answer. An answer that requires more than one reading to be understood because it has only weak linkages between cause and effect and contains inconsistencies may only be awarded one mark or less.
Have you ever wondered how identical twins are formed? Are they really products of the same original cell with exactly the same genetic information in every cell of their bodies? Why do they not behave in exactly the same way? How is it possible for them to have differences?

These questions generally cause confusion until some of the mysteries of heredity are unveiled. As the interactions between cells and their environment is explored in this section, you will begin to understand the unique nature of every form of life as an expression of a genetic code.
ACTIVITY

1 What’s in Chromosomes?

Has someone ever confused you with an older brother or sister? Perhaps a teacher has recognized you even before finding out your name. You may have heard that you have your mother’s eyes, your father’s nose, or your uncle’s ears. Why do members of a family tend to look alike?

Part of the answer to this question is found in understanding chromosomes and what’s in them. To learn about this source of heredity read pages 494 to 496 in your text. After reading the first four sections, answer the following questions.

1. What is a gene and how is it related to a chromosome?

2. List at least three examples of technology that have enhanced the study of chromosomes.

3. Describe the relationship between cytology and genetics.

4. Summarize each point of the chromosomal theory by drawing a schematic diagram of each of the following concepts:
   - Chromosomes carry genes.
   - Paired chromosomes segregate during meiosis.
   - Chromosomes assort independently during meiosis.
   - Chromosomes contain many different genes.

Check your answers by turning to the Appendix, Section 1: Activity 1.

Experimentation is used to both verify and falsify a scientific hypothesis. When the testing is carefully controlled, the conclusions made are valid interpretations of the data collected. Early genetic tests were performed by Thomas Hunt Morgan and others. To learn about his work and contribution to the study of heredity, read pages 496 to 500 in your text. When you have finished reading, answer the following questions.

5. How did Morgan discover sex-linked traits?

6. Differentiate between autosomes and sex chromosomes.

7. Complete Review questions 1, 2, and 3 from page 500 of your text.

Check your answers by turning to the Appendix, Section 1: Activity 1.
To gain practical experience in discovering what's in chromosomes, perform the laboratory Human Sex-Linked Genes found on page 502 of your text.

**Investigation: Human Sex-Linked Genes**

**Objective**

Investigate the inheritance of colour blindness.

**Materials**

- colour blindness chart found on page 502 of your text

**Procedure**

Complete Procedure steps 1, 2, and 3, testing yourself, members of your family, friends, and any other population you have access to such as a class at school.

**Observations**


**Analysis and Interpretation**

9. Complete the Laboratory Application questions 1, 2, 3, and 4 on page 502.

Check your answers by turning to the Appendix, Section 1: Activity 1.

In this activity you have studied evidence that chromosomes carry genetic information. Next you'll learn where the information to produce the observable characteristics of a living organism is actually located on chromosomes.

**ACTIVITY 2**

**Mapping Chromosomes**

Have you ever tried to navigate through a large city? A road map is helpful, but signs and distances are essential. Remember that the roads are built first; then the signs are erected and a road map is created to make the roads easier to use. Getting from one site to another can involve many different paths on many different occasions. Successful navigation includes avoiding getting lost.
It is easy to get lost in the "city of genetics," but you have already learned some of the important road signs. Reread pages 471 to 475 in your text and complete the following questions before proceeding with this activity.

1. Define each of the following terms.
   - gene or allele
   - genotype
   - phenotype
   - homozygous
   - heterozygous
   - homologous
   - dominant
   - F_1
   - F_2
   - segregation
   - gamete
   - recessive

2. Describe the value of performing test crosses. Use examples in your description.

Check your answers by turning to the Appendix, Section 1: Activity 2.

With these "roads" in mind, carefully read the section entitled Gene Linkage and Crossing-Over on pages 503 and 504 of your text. After reading, answer the following questions to reveal the major "signs."
3. Using Figure 21.9 on page 503, draw the cell and its chromosomes that is represented by the F₁ generation AaBb. Explain the linkages in the gametes.

4. Using Figure 21.10 on page 503, draw the cell and its chromosomes that is represented by the F₁ generation AaBb. Explain the linkages in the gametes.

5. Perform a test cross on paper with each of the gametes produced in Figure 21.9 crossed with a *homozygous recessive* gamete. Find and compare the theoretical ratio of the phenotypes of the test cross offspring.

6. Now perform the same test cross with each of the gametes produced in Figure 21.10 crossed with a homozygous recessive gamete and find the phenotypic ratio of the test cross offspring.

7. Explain why the actual results in Figure 21.11 on page 504 differ from the theoretical results in question 6.

Check your answers by turning to the Appendix, Section 1: Activity 2.

Now that you have identified the key "signs" in the "city of genetics," it is time to make the map. Carefully read the section entitled Mapping Chromosomes on pages 504 and 505; then answer the following questions.

8. How is a gene marker like a sign on a road map?

9. If there were 50 recombination phenotypes in 250 offspring, what is the map distance between the linked alleles? Check Figure 21.11 on page 504 for a clue.

A three-point test cross is performed to identify the locus of each of three alleles in relation to each other. The results were as follows:

\[
\begin{align*}
AB \text{ recombinations} &= 225 \\
BC \text{ recombinations} &= 165 \\
AC \text{ recombinations} &= 60 \\
\text{Parental linkages} &= 550 \\
\text{Total offspring} &= 1000
\end{align*}
\]

10. Show the position and map distance apart for each allele (A, B, and C) on a chromosome. Calculate the map units; then draw the chromosome.

Check your answers by turning to the Appendix, Section 1: Activity 2.
Are you lost in the city of genetics yet? You have raced through the roads, glanced at the signs, and had your first trial using the map. To gain more practical knowledge in this adventure in heredity, perform the Case Study: Mapping Chromosomes as found on pages 506 and 507 of your text.

**Investigation: Mapping Chromosomes**

**Objective**

Use cross-over frequencies to construct a gene map.

**Background Information**

Read the Background Information on page 506. Notice that A. H. Sturtevant began with an hypothesis.

**Procedure**

Complete steps 1 to 3.

It should be noted that the term *chromatid* refers to the replicated chromosome that shows the result of crossing-over. Each of the chromosomes shown in the gametes of Figures 21.9 and 21.10 are, in fact, chromatids. Remember that homologous chromatids will pair up after fertilization restoring the “two-allele” condition for traits in the offspring.

**Observations**

11. Complete Procedure questions a to f from page 506 of your text.

**Analysis and Interpretation**

12. Complete the Application questions 1 to 4 from pages 506 and 507.

Check your answers by turning to the Appendix, Section 1: Activity 2.

Just like navigating a new freeway, learning about the chromosome maps in the nucleus of a cell can be a challenging task. The first time through, however, can be successful if careful attention is given to the “signs” and “roads.”

In the next section you will learn more about the composition of chromosomes and how genes produce traits.

---

1 Courtesy of J. Kuspira and R. Bhambhani, Department of Genetics, University of Alberta.
Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

In this section you have learned about chromosomes and heredity. The structure of a chromosome has shown that many genes are linked together in producing the genetic code. Mapping the location of each gene on a chromosome is a complicated process.

1. A colour-blind father (X\textsuperscript{Y}) and a normal mother (X\textsuperscript{O}X\textsuperscript{O}) whose mother was colour-blind have three children. Using a Punnett square, show what the possible genotypes and phenotypes of their sons and daughters would be.

2. Review Figure 21.10 on page 503 in your text and draw a diagram to illustrate the crossing-over that produces the gene linkages shown in the gametes.

Careful experimentation with fruit flies (Drosophila melanogaster) has produced complete chromosome maps. Review Figure 21.12 on page 504 in your text and answer the following questions. Remember that normal characteristics are considered wild and mutant characteristics are recessive.

3. What are the positions for the alleles that produce the following?
   a. wild-type (grey) body colour
   b. mutant eye colour
   c. normal wings
   d. short legs

4. Determine the crossover frequencies between the following:
   a. grey body and long legs
   b. dumpy wings and short feelers
   c. vestigial and curved wings

Check your answers by turning to the Appendix, Section 1: Extra Help.
5. Complete the following crossword puzzle as a review of some of the most common terms used in this module so far.

Across

c. the separation of homologous chromosomes during meiosis
d. XY in humans and Drosophila
g. genes found on the same chromosome
h. the physical expression of genotype
i. developed the original techniques to map chromosomes
l. the gene that specifies gender
m. Aa
n. chromosomes with the same sequence of genes
p. a researcher who called the separation of threads in the nucleus “mitosis”
q. an allele
s. the body or dark spot in the somatic cells of females
t. a German scientist who observed chromosomes in pairs
u. genes that help identify the position of other genes
Section 1: Genes and Chromosomes

Down

1. believed heredity was in male semen
2. the cell produced by meiosis
3. American biologist who observed and described chromosomes in pairs
4. experimented with garden peas
5. new gene linkages produced by crossing-over
6. chromosome pairs that are common to males and females
7. a sex-linked "bleeder" disease
8. the location of a gene on a chromosome
9. XX in humans and Drosophila
10. researcher who discovered sex-linked traits

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

1. On page 514 of your text there are questions that help you apply the concepts presented in this section. Do one or more of the following:

- Textbook question 2
- Textbook question 4
- Textbook question 8
- Textbook question 3
- Textbook question 5

2. If you have a copy of the laser videodisc The Living Textbook, view the following sections to increase your understanding of chromosomes and heredity.

- chromosomes 1640-1642, 2818
- Drosophila 1720-1727
- sex chromosome 3194
- sex-linked characteristics 3195
- crossing-over 2855
- recombination 3169

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

So now you've learned that genes are on chromosomes in definite locations and the locations can be determined with a gene map. This represents a significant advance in your knowledge of genetics, but knowing where genes are located on a chromosome is only part of the story of heredity. Next you'll study how gene information is stored in genes and how the molecules of heredity control all life forms.
Section 1 Assignment: Genes and Chromosomes

Review the Evaluation information found in the introductory pages of this module.

It is important to number and clearly identify each page with the following information at the top:

Biology 30 - Module 5  Section 1 Assignment  Page #  Name and ID#

Be sure to write legibly. Leave a wide left margin and number all of your pages.

Carefully read each of the following multiple-choice questions and decide which of the choices best completes the statement or answers the question. Each question is worth 1 mark.

1. The hereditary factors that an individual will pass on to his or her offspring are determined by his or her

   A. environment
   B. cytoplasm
   C. phenotype
   D. genotype

2. A genotype consists of two identical alleles for a certain trait. This trait is expressed only when the two alleles are identical. The genotype is

   A. homozygous dominant
   B. homozygous recessive
   C. heterozygous dominant
   D. heterozygous recessive

3. A test cross is one in which the organism to be tested is mated with an organism that is

   A. heterozygous for the trait
   B. homozygous dominant for the trait
   C. homozygous recessive for the trait
   D. of the same genotype as the organism that is being tested

4. A certain man has the genotype $AaBb$; genes $A$ and $B$ are on one chromosome, and $a$ and $b$ are on the homologous chromosome. Suppose crossing-over occurs during a meiotic division in this man's testis. With regard to the two genes discussed here, how many genetically different types of sperm cells will result?

   A. one
   B. two
   C. four
   D. eight
5. Singer Arlo Guthrie has a 50% chance of dying prematurely from Huntington’s chorea, the same genetic disease that killed his father, Woody Guthrie. Neither Woody Guthrie’s mother nor Arlo Guthrie’s mother carries any allele for this disease. What type of inheritance pattern does this disease have? (It can be determined from the information given.)

A. autosomal dominant  
B. sex-linked dominant  
C. autosomal recessive  
D. sex-linked recessive

6. Hemophilia is a genetic disease that has plagued the royal houses of Europe since the time of England’s Queen Victoria, who was a carrier. Her granddaughter Alexandra married Nicholas II, the last Tsar of Imperial Russia. Alexandra was a carrier of the gene for hemophilia; Nicholas was normal. Their son, the Tsarevich Alexis, was afflicted with the disease. Alexis and his four sisters are all thought to have been killed at the outbreak of the Revolution of 1917. It is likely that

A. all four sisters were fully normal with regard to hemophilia  
B. one or more of the sisters may have been a carrier of hemophilia  
C. all of the sisters were carriers of hemophilia  
D. one or more of the sisters may have had hemophilia

7. A human disease called pseudohypertrophic muscular dystrophy is inherited as a sex-linked recessive trait. The disease is characterized by a wasting away of the muscles, beginning at about age 6, so that by the time affected persons are in their teens they are almost literally skin and bones; they usually die before reaching adulthood. Suppose, however, that a boy with the disease lives past puberty and marries a woman heterozygous for the trait. If they have a son, what is the probability that he will have the disease?

A. 25%  
B. 50%  
C. 75%  
D. 100%

8. Theoretically, if a female hemophiliac married a normal male, what percentage of their male offspring would be expected to have hemophilia?

A. 100%  
B. 50%  
C. 33.3%  
D. 25%
9. Individuals that were homozygous dominant for genes C and E were crossed with homozygous recessives, and the F\(_1\) generation was test-crossed. Given the following chromosome map, if there were 500 offspring from this test cross, how many would you predict would be recombinant?

```
C   D   E   F
\[4 \quad 6 \quad 10\]
```

A. 25  
B. 40  
C. 50  
D. 100

10. The crossing-over frequency between genes A and B is 7%; between B and C, 17%; between C and D, 4%; between A and C, 10%; and between B and D, 13%. What is the frequency of crossing-over between A and D?

A. 6%  
B. 8%  
C. 10%  
D. 15%

11. The crossing-over frequency between linked genes A and B is 2%; between B and C, 11%; between C and D, 3%; between D and A, 12%; and between C and A, 9%. The sequence of these four genes on the chromosome is

A. DABC  
B. CBAD  
C. BACD  
D. ABCD

12. In *Drosophila*, flies homozygous dominant for grey body and normal wings were crossed with flies that were homozygous recessive for black body and small wings. The F\(_1\) progeny were test-crossed, with these results:

- grey, normal wings: 410  
- black, normal wings: 105  
- grey, small wings: 95  
- black, small wings: 390

These data indicate that

A. the genes for body colour and wing size are on different chromosomes  
B. the genes for body colour and wing size are completely linked (next to each other on the chromosome)  
C. genes for body colour and wing size are linked and are 10 units apart on the chromosome  
D. genes for body colour and wing size are linked and are 20 units apart on the chromosome
Use the following information to answer question 13.

Mendel's laws are as follows:

**Segregation:** An organism's characteristics are controlled by factors (genes) which are normally carried in pairs, but which occur singly in the gametes.

**Independent Assortment:** Alleles of genes independently segregate (separate) of one another during the formation of gametes.

The chromosome theory by Sutton and Boveri explains exceptions to the First and Second Laws.

13. a. Using diagrams and descriptions, explain one exception to Mendel's First Law and one exception to Mendel's Second Law. (6 marks)

b. Provide two examples of technology (procedures, equipment) that are used to help explain these exceptions. (2 marks)

14. A cross is carried out between two pure lines of a plant, one having smooth, coloured seeds and the other having wrinkled, white seeds. The F₁ seeds obtained are all smooth, coloured. The F₁ individuals are then crossed with one another.

a. Describe the qualitative and quantitative results (as proportions of the total) that would be expected for the F₂ generation on the basis of the theoretical application of Mendel's laws to this experiment? (1 mark)

b. The F₂ progeny obtained are distributed thus:
   - smooth, coloured seeds: 5125
   - wrinkled, coloured seeds: 122
   - smooth, white seeds: 125
   - wrinkled, white seeds: 1628

   Compare the quantitative results (as proportions of the total) actually obtained in the cross in F₂ with the theoretical Mendelian results. (2 marks)

c. To interpret the actual results, geneticists decided to carry out a test-cross of the F₁. What is the principle of such an experiment and what is its value? (2 marks)

d. The results of this test-cross are as follows:
   - smooth, coloured seeds: 2406
   - wrinkled, coloured seeds: 93
   - smooth, white seeds: 92
   - wrinkled, white seeds: 2409

   Calculate the percentages (to one decimal place) of these different categories. (1 mark)
e. Give genetic interpretations of the results of this test-cross and of the initial cross. (2 marks)

f. What genetic application can be made of the percentages which you calculated in d.? (2 marks)

Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

| Self: A. | B. | C. | D. | E. | F. |
| Teacher: A. | B. | C. | D. | E. | F. |

15. In Drosophila, non-wild-type (recessive) alleles are sc (scute, or loss of certain thoracic bristles), ec (echinus, or roughened eye surface), and cv (crossveinless, or absence of a cross vein on the wing). You cross flies homozygous for sc, cv, and ec with homozygous (dominant) wild-type to get triple-heterozygote females, which you then test-cross to obtain the following progeny:

| sc | cv | ec | 417 |
| + | + | + | 430 |
| sc | + | + | 25 |
| + | cv | ec | 29 |
| sc | + | ec | 44 |
| + | cv | + | 37 |
| + | + | ec | 0 |
| sc | cv | + | 0 |

a. Is there gene linkage involved? Explain your answer. (1 mark)

b. Draw a map of the genes, showing their order and their distance apart in map units. Show all your work. (4 marks)

Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.
16. Eleanor Perkins and her husband, Garvey, are phenotypically normal, but Eleanor’s family has its share of sex-linked abnormalities. Her brother, Arthur, and her son, Chester, both suffer from hemophilia. Her father is not hemophiliac, but he is colour-blind.

a. Eleanor knows she is a carrier. Which X-linked gene(s) does she have?  
(2 marks)

b. Once grandpa came to breakfast wearing one red sock and one green sock. Everyone laughed (Eleanor, Garvey, and Arthur), but Chester did not get the joke. Suddenly Eleanor realized he was colour-blind, too. What must have happened in one of her oocytes shortly before her birth?  
(1 mark)

c. Eleanor and Garvey are expecting another child. If it is a daughter, what are the probabilities for hemophilia and for colour blindness?  
(2 marks)

Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

<table>
<thead>
<tr>
<th>Self:</th>
<th>A.</th>
<th>B.</th>
<th>C.</th>
<th>D.</th>
<th>E.</th>
<th>F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher:</td>
<td>A.</td>
<td>B.</td>
<td>C.</td>
<td>D.</td>
<td>E.</td>
<td>F.</td>
</tr>
</tbody>
</table>
Have you ever wondered how it is possible to create a beautiful building out of wood, concrete, metal, and glass? Can you imagine the detail that must go into the plans so everything fits perfectly? The quality of the building is directly related to how well the blueprint is drawn up by the architect and how well it is followed by the builder.

In this section you will learn how the blueprints for life are written in cells. You will also find out how these plans are followed to create a living organism.
In Section 1 you learned that chromosomes contain the genes for all the traits in living organisms. Now you will learn more about the building blocks of life – DNA. Read pages 516 and 517 in your text and answer the following questions.

1. Complete Review questions 1 to 5 on page 522 in your text.

Check your answers by turning to the Appendix, Section 2: Activity 1.

The blueprint for the transmission of traits from parents to offspring is the genetic code in DNA. To learn more about the workings of inheritance, complete the Case Study: Evidence of Hereditary Material found on pages 518 and 519 in your text.

**Investigation: Evidence of Hereditary Material**

**Background Information**

Read the Background Information on page 518 in your text. Notice that there are two types of pneumonia bacteria. Only one, the cells with capsules, is deadly.
Objective

The objective of this investigation is to analyse experimental data.

Procedure

Carefully read steps 1, 2, and 3 in Procedure. Follow the sequence of the laboratory procedure in the diagrams on page 518 and 519.

Observations

2. Complete Procedure questions a to e on pages 518 and 519.

Analysis and Interpretation

3. Complete the Case Study Application questions 1 to 3 on page 519.

Because the genetic code can be transferred from one cell to another and change the resulting characteristics, what is really in DNA and how is it put together? To learn about the discovery of the structure of DNA, read pages 520 to 522 in your text. After you have finished reading, answer the following questions on page 522.

4. Complete Review questions 6 to 8 found on page 522.

The great mystery of heredity is solved in part by understanding how DNA is copied and decoded. To learn about these processes, read page 523 in your text and answer the questions on page 527.

5. Complete Review questions 9 to 13.

View the ACCESS Network video, Protein Synthesis, Part 2 DNA: Molecule of Heredity and Part 3 DNA Replication. Familiarize yourself with the following questions first. As you view the video, answer the questions. Stop the tape whenever necessary.
6. Describe the importance of proteins in the construction and regulation of a cell.

7. Explain the basic structure of DNA.

8. What constitutes a full complement of DNA?

9. How are identical copies of DNA produced in cells before cell division?

Check your answers by turning to the Appendix, Section 2: Activity 1.

Investigation: Exploring DNA Replication

Objective

Investigate how the double helix of DNA replicates.

Materials

- scissors*
- toothpicks*
- transparent tape*
- page of symbols for DNA
- blank sheet of paper*

* supplied by student

Procedure

Complete steps 1 to 8 in the laboratory on pages 525 and 526 in your text. You may choose not to use toothpicks as described in the text and instead fit the pieces directly together.

Observations

10. Complete Procedure questions a to e on pages 525 and 526 in your text.

Analysis and Interpretation

11. Complete Laboratory Application questions 1 to 5 on page 526 in your text.

Check your answers by turning to the Appendix, Section 2: Activity 1.
Genes are portions of the sequence of nitrogenous bases in DNA that code for certain traits. This seems pretty simplistic especially when you consider that the language of nucleic acids only has four letters (A, T, G, C).

And remember, in DNA A pairs with T and C pairs with G.

If somebody asks you why, say because A and T share two weak bonds while C and G share three bonds.

The complexities of decoding, copying, and translating are the subject of the next activity.

**ACTIVITY 2 From Code to Trait**

Have you ever assembled a chemical model? Maybe you have put together a new bicycle or a model airplane. Each of these tasks can be challenging even if you have a precise set of instructions. Most of the time the finished product accurately represents the plans and you can sit back with a sense of real satisfaction over a job well done.
Every cell in every organism functions in the same basic way because cells are composed of the same basic materials. To learn about this concept read Importance of Proteins on pages 532 and 533 in your text. After reading, answer the following questions.

1. Identify the two major roles that proteins play in the normal activity of cells.

2. Amino acids are the building blocks for proteins. If each different amino acid in your body were identified by a letter of the alphabet, respectively, identify the following protein words by placing the corresponding letter for each number on the line. Hint: Let a = 1, b = 2, c = 3, d = 4, etc.

   a. 2 9 15 12 15 7 25
   b. 16 18 15 20 5 9 14 19
   c. 7 18 5 1 20

3. Rearrange the sequence of the numbers for each protein word in question 2 and create at least one new protein word for each. They need not be actual English words, just complete groups of letters.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Using the knowledge that proteins are produced from genes and that changes in the amino acid sequence of a protein means a change has occurred in the gene, read One Gene, One Protein on pages 533 and 534 in your text. After reading, answer the following questions.

4. In Figure 23.2 on page 533 in your text the role of enzymes in a reaction pathway is illustrated. Explain the effect of altering enzymes 1, 2, and 3 as you altered the protein words in question 3.

5. How many genes make the complete pathway possible?

6. Discuss the potential impact of Beadle and Tatum’s research on subsequent studies in genetics.

Check your answers by turning to the Appendix, Section 2: Activity 2.
What happens in a cell to allow the nucleus to exert its influence on the activity of the rest of the cell? How is the sequence of base pairs in the DNA of a chromosome decoded to produce a specific sequence of amino acids in an enzyme? To explore the answers to these questions, read pages 534 and 535 in your text. Answer the following questions after you finish reading.

7. Draw and label a chromosome that is made of three genes; one fourteen codons long, one eleven codons long, and one twenty-seven codons long. Indicate the number of base pairs in each gene.

8. Using Table 23.1 on page 535 in your text, identify the amino acid sequence for the RNA codon sequence shown in Figure 23.4. Match the RNA codons to the amino acids in Table 23.1.

<table>
<thead>
<tr>
<th>DNA</th>
<th>TAC</th>
<th>GGA</th>
<th>TTG</th>
<th>CAG</th>
<th>CAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>RNA</td>
<td>AUG</td>
<td>CCU</td>
<td>AAC</td>
<td>GUC</td>
<td>GUA</td>
</tr>
</tbody>
</table>

Amino acid sequence for RNA:

9. Answer Review questions 1 and 2 on page 537 in your text.

Check your answers by turning to the Appendix, Section 2: Activity 2.
Now complete the picture of protein synthesis by reading pages 536 and 537 in your text. Answer the following questions after you finish reading.

10. Complete Review questions 3 to 7 on page 537.

Check your answers by turning to the Appendix, Section 2: Activity 2.

View the ACCESS Network video, Protein Synthesis, Part 4 RNA Synthesis (10 min) and Part 5 Transfer RNA (10 min). Familiarize yourself with the following questions first. As you view the video, answer the questions. Stop the tape whenever necessary.

11. Complete the following chart which compares DNA and RNA.

<table>
<thead>
<tr>
<th>Nucleic Acid</th>
<th>Sugar</th>
<th>Helix</th>
<th>Size</th>
<th>Site</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RNA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12. Why did researchers believe a codon was made from three nucleotides instead of two or one?

13. What is the purpose of an mRNA tail of 200 adenine nucleotides?

14. Explain the vital role of tRNA in protein synthesis.

15. Discuss the impact of ribosomes on protein synthesis and construct a flowchart of transcription, translation, and synthesis.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Investigation: The Synthesis of a Protein

Objective

Investigate how a protein is synthesized from the information within a gene.

Materials

- transparent tape*
- scissors*
- Table 23.1 on page 535 in your text
- page of symbols for DNA
- blank sheet of paper*
- page of symbols for RNA

*supplied by student

See the tear-out pages in the Appendix.
Procedure

- You will be supplied with a page of symbols representing DNA, mRNA, tRNA, and amino acids. Cut out the individual molecules.

- Arrange the DNA sequence as TAC, ACG, ATA, ACA, TCC, AAA, CAA, GTT, GGA, TTA, ATT.

- Make the mRNA transcript by matching the complementary mRNA nucleotides to the DNA template. Some mRNA nucleotides may have to be turned over. Tape all the mRNA codons together to form one molecule. Remove the mRNA molecule from the DNA template.

- Match the corresponding tRNA anticodons to the mRNA transcript.

- Using Table 23.1 on page 535 in your text, match the appropriate amino acid to each tRNA.

- Tape the amino acids together to produce the protein.

Remember: The amino acids correspond to the mRNA codons not the tRNA anticodons. You’ll discover which tRNA attaches to each amino acid.

Observations

16. Complete the following chart.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Number of Subunits</th>
<th>Sequence of Subunits</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mRNA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein (amino acid sequence)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

17. What role did you fill in this simulation of transcription, translation, and protein synthesis?

Analysis and Interpretation

18. Describe the similarities and differences between the DNA codons and the mRNA codons.

19. What does the mRNA transcript represent?
20. How would a substitution of C for the first A in the DNA AAA code affect the protein produced?

Check your answers by turning to the Appendix, Section 2: Activity 2.

So DNA is the code in the nucleus.

mRNA copies the code and leaves the nucleus.

And tRNA matches the mRNA sequence and brings along amino acids.

The amino acids are assembled in a sequence to make a protein.

From code to trait is quite a process – transcription, translation, protein synthesis, and enzymatic functions in reaction pathways.

Imagine a language based on words made of twenty different letters. With no limit on the combinations of letters or the numbers of letters per word, how many different words could be made? The number is nearly infinite. Such is the secret of DNA.

The impact of errors in this whole process can be devastating. You will investigate the nature of genetic disorders in the next section and learn about technology that may solve many of these problems.

**Follow-up Activities**

If you had difficulty understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.
Biochemistry

Extra Help

In this section you have learned that the molecules of heredity are nucleic acids in DNA and RNA.

Using Figures 22.5 and 22.6 on page 522 in your text, answer the following questions.

1. Adenine and guanine are purines. Cytosine and thymine are pyrimidines. Explain why each base will only bond with one complementary base in the formation of a DNA molecule.

2. If the portion of the DNA molecule shown in Figure 22.6 represents the genetic code for a single gene, then how many base pairs and codons are in this gene?

   **Hint:** Count the rungs in the ladder.

3. Describe what must happen for DNA replication to begin.

4. Complete the complementary strand for the following single DNA helix. Also show the hydrogen bonds. Draw both strands.

<table>
<thead>
<tr>
<th>Old</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>T</td>
</tr>
<tr>
<td>T</td>
<td>C</td>
</tr>
<tr>
<td>C</td>
<td>G</td>
</tr>
<tr>
<td>G</td>
<td>C</td>
</tr>
<tr>
<td>T</td>
<td>A</td>
</tr>
</tbody>
</table>

Check your answers by turning to the Appendix, Section 2: Extra Help.
Decoding the genetic information in a chromosome involves copying and translating.

Use the previous diagram and the following word list to complete question 5.

- amino acid
- enzymes
- genes
- mRNA
- traits
- translation
- nucleotides
- protein
- ribosome
- sequence
- transcription
- tRNA

5. A chromosome is composed of many __________, each of which will affect the __________ of the cell. The sequence of DNA __________ is very specific. The result of DNA __________ is the synthesis of a complementary copy of the gene. The __________ strand produced will migrate to the cytoplasm from the nucleus. A __________ will attach to the transcript and begin the process of __________. This process involves special __________ molecules which have an anticodon at one end and an __________ at the other. Complementary base pairing will ensure that the correct __________ will be maintained when the __________ is formed. This synthesis will produce specific __________ that catalyze reaction pathways in a cell.
6. Using the obligatory base pairing rule and Table 23.1 on page 535 in your text, complete the following simulation by filling in the mRNA codons and naming each amino acid in the protein.

DNA codons
T A C T T C G C A T A C C G A G C C A G T A T T

mRNA codons

Amino acids

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

At the end of chapters 22 and 23 in your text there are questions that help you apply the concepts you have learned in this section. Do one or more of the following:

1. Textbook question 3 on page 530
2. Textbook question 7 on page 531
3. Textbook question 4 on page 552
4. Textbook question 6 on page 552
5. Textbook question 8 on page 552

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

Discovering the delicate pathway from genetic code to physical trait hastens the journey through the world of heredity. The precision of this pathway is amazing, yet rather straightforward. Languages of codes and actions are copied and translated with accuracy so traits can be expressed normally. However, there are mistakes that lead to some interesting abnormalities. Can an understanding of the process of molecular heredity lead to the ability to change and control it? Should genetic manipulation be allowed?
Section 2 Assignment: The Molecules of Heredity

Review the Evaluation information found in the introductory pages of this module.

It is important to number and clearly identify each page with the following information at the top:

Biology 30 – Module 5  Section 2 Assignment  Page #  Name and ID#

Be sure to write legibly. Leave a wide left margin and number all of your pages.

Carefully read each of the following multiple choice questions and decide which of the choices best completes the statement or answers the question. Each question is worth 1 mark.

1. Purine nucleotides mainly differ from pyrimidine nucleotides in their number of

   A. nitrogen rings in the base  
   B. phosphate groups in the nucleotide  
   C. oxygen atoms in their sugars  
   D. sugars in the nucleotide

2. The faithful replication of DNA, prior to cell division, depends primarily upon

   A. the genetic code  
   B. the availability of uracil  
   C. the action of ribosomes  
   D. the principle of base-pairing

3. According to the Watson-Crick model of the helical structure of DNA, the outer "sides" are composed of

   A. purines and sugars  
   B. sugars and phosphates  
   C. pyrimidines and phosphates  
   D. purines and pyrimidines

4. In most living things the direction of transfer of genetic information is

   A. protein → DNA → mRNA  
   B. DNA → mRNA → protein  
   C. DNA → tRNA → protein  
   D. protein → tRNA → DNA
5. Transfer RNA mainly functions in
   A. carrying RNA from the ribosomes to mRNA
   B. attaching RNA to the ribosomes
   C. carrying mRNA from the nucleus to the cytoplasm
   D. carrying amino acids to the correct site on the mRNA

6. Which one of the following structures will be coded for by the shortest sequence of DNA?
   A. a tRNA having 75 nucleotides
   B. a mRNA having 75 codons
   C. a polypeptide composed of 75 amino acids
   D. a protein composed of 2 polypeptides, each 35 amino acids long

7. How many tRNA molecules would be necessary to produce protein containing 120 amino acids? (Assume that a given tRNA is used only once.)
   A. 40
   B. 60
   C. 120
   D. 240

8. What sequence of amino acids would be created by the DNA template sequence GTCTATTTCCCG if the mRNA genetic code for amino acids is as follows?

<table>
<thead>
<tr>
<th>mRNAs</th>
<th>amino acid (by number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAG</td>
<td>1</td>
</tr>
<tr>
<td>AUC\</td>
<td>2</td>
</tr>
<tr>
<td>AUA/</td>
<td></td>
</tr>
<tr>
<td>GGC\</td>
<td>3</td>
</tr>
<tr>
<td>GGG/</td>
<td></td>
</tr>
<tr>
<td>UAU</td>
<td>4</td>
</tr>
<tr>
<td>UUC</td>
<td>5</td>
</tr>
<tr>
<td>CAG</td>
<td>6</td>
</tr>
<tr>
<td>GUC</td>
<td>7</td>
</tr>
<tr>
<td>CCG</td>
<td>8</td>
</tr>
</tbody>
</table>

   The amino acid sequence (by number) would be
   A. 7-4-5-3
   B. 6-2-1-3
   C. 7-4-5-8
   D. 6-4-5-8
9. Consider the metabolic pathway in the following *Neurospora* diagram, where Gene *a* corresponds to Enzyme *A*, etc. Predict the response if a mutation occurred in Gene *b* that affected its normal function.

![Diagram of metabolic pathway](image)

A. This mutant strain would only survive on a minimal medium, that is, one containing minimal nutritional requirements.
B. This mutant strain would only survive on a medium to which Compound B has been added.
C. This mutant strain would only survive on a minimal medium also containing Compound A.
D. Compound B would accumulate.

**Questions 10 and 11 assume that a gene possesses this base sequence:***

```
ATAGCATggAATACGCGA
```

10. Which of the following mutations would most likely produce the greatest change in the amino acid sequence of the polypeptide coded for by this gene?

A. substitution of G for A at position 2
B. addition of T between positions 2 and 3
C. deletion of C at position 4
D. substitution of T for C at position 5

11. Exposure to X-ray radiation will cause a mutation in this gene such that the codon labelled X is changed to GGT. This alteration will result in

A. all codons following X being misread
B. only codon X being misread
C. all codons prior to X being misread
D. no change in the polypeptide coded for by this gene

12. A biochemical analysis of a sample of DNA extracted from a cell showed that 34% of the nitrogenous bases were cytosine. This means that there is

A. 16% thymine
B. 16% guanine
C. 34% adenine
D. 34% guanine
Use the following information to answer question 13.

In 1953 the structure of DNA was published by Watson and Crick. They ended their paper with these words: "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material." The mechanism they suggested is shown in the following illustration.

Because each new double-helix molecule would be half old and half new, such replication was called "semi-conservative."

In 1957 Meselson and Stahl did an experiment that confirmed the Watson-Crick hypothesis: DNA replication is semi-conservative. In this experiment, the bacterium *E. coli* was grown in a medium in which the nitrogen source was \(^{15}\text{N}\) and produced a higher density (heavy) culture. A second culture was grown in \(^{14}\text{N}\) producing a lower density (light) sample. Transferring each culture into a new medium and testing them after one and two generations of replication provided the verification of the mechanism for DNA replication.
13. a. Describe the mechanism of replication that gave the results in cultures C and D. Illustrate your answer. (5 marks)

b. Predict the results in cultures E and F. Illustrate your answer. (5 marks)

Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

<table>
<thead>
<tr>
<th>Self:</th>
<th>A.</th>
<th>B.</th>
<th>C.</th>
<th>D.</th>
<th>E.</th>
<th>F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher:</td>
<td>A.</td>
<td>B.</td>
<td>C.</td>
<td>D.</td>
<td>E.</td>
<td>F.</td>
</tr>
</tbody>
</table>

14. Read Frontiers of Technology: The Ames Test on pages 546 and 547 in your text and answer the following questions.

a. Identify three advantages of the Ames test over other methods. (1 mark)

b. Briefly describe what the Ames test involves. (1 mark)

c. Describe the relationship that is assumed between a chemical that alters DNA and cancer. (1 mark)

d. Using Chemical A as an example, clearly state a hypothesis based on the Ames test. (1 mark)

Use these graphs to answer question e.

![Bacterial Growth Graphs]

- Substance A
- Substance B
- Substance C plus liver enzyme

e. Which graph (or graphs) demonstrates a harmless substance. Support your answer and compare your choice to the other graph(s). (1 mark)
f. A mutant strain of bacteria is used as the basis for the Ames test. What is unique about this strain and how is it used? (1 mark)

g. Explain how growth of the bacteria indicates carcinogenic potential. (1 mark)

h. Describe the control component in an Ames test. (1 mark)

i. Identify the response variable in an Ames test. (1 mark)

j. Why are test chemicals sometimes mixed with liver enzymes? (1 mark)

15. Assume that the production of an important hormone depends on a simple enzyme and cells require a particular DNA sequence to control production of the enzyme. As a protein, let the enzyme consist of a ten amino acid sequence: leucine – alanine – alanine – cysteine – glycine – leucine – proline – leucine – valine – lysine. In DNA, TAC is the initiator and ATT is the terminator codon for the code for this enzyme.

Using Table 23.1 on page 535 in your text, find and correct the DNA code in this mutated sequence so this enzyme can be produced. Illustrate the corrected sequence.

DNA Sequence

TACAATCGACGGACACCTGATTAATCAATTTATT (8 marks)

Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

<table>
<thead>
<tr>
<th>Science Skills</th>
<th>A. Initiating</th>
<th>B. Collecting</th>
<th>C. Organizing</th>
<th>D. Analysing</th>
<th>E. Synthesizing</th>
<th>F. Evaluating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DNA controls the structure, function, and ultimately the behaviour of all living things including humans. Imagine this. Three-and-a-half million years ago an early human uses a sharp piece of flint to make a neat hole in an ostrich egg. The egg shell will become a useful drinking vessel. Three-and-a-half million years later a contemporary human floats in space above the Earth and uses a ratchet tool to release the clasps holding a satellite in the loading bay of a space shuttle. The satellite will become a communication link for thousands of humans on Earth. What role has DNA played in the behaviour of these humans? Has DNA been in control all this time? How powerful is DNA? Should it be left alone? Knowledge and technology now exist that enable humans to manipulate the very substance that controls who and what they are and perhaps what they may do. In this section you’ll explore some of the possibilities.
ACTIVITY

1 Mutation: An Error with a Purpose

Have you ever seen a dwarf or a giant? Maybe you have observed someone who has a cleft palate and wondered how this abnormality occurred. Perhaps you were born without enamel on your teeth, so they needed to be capped or replaced because they were so soft. Mutations are all around you but what are they and how do they occur?

To answer these questions and discover how the answer lies in DNA, read pages 539 to 540 in your text. After you have finished reading, answer the following questions.

1. Complete Review questions 8, 9, and 10 on page 547 in your text.

Check your answers by turning to the Appendix, Section 3: Activity 1.

The idea that chromosomes and genes can change is not a new one. Over fifty years ago, a brilliant biologist, Barbara McClintock, defied tradition with a new theory. To review gene recombinations and learn about this remarkable woman, read pages 507 to 509. After reading, answer the following questions.

2. How are transposons similar to mutations?

3. Discuss the impact of transposable genes in the activities of bacteria.

4. Gene mapping enables scientists to identify specific sites of mutation. Briefly describe the role of radioactive labels and gel electrophoresis in identifying the human genome.

Check your answers by turning to the Appendix, Section 3: Activity 1.

If you have access to supervised laboratory facilities, do Part A.
If you do not have access to laboratory facilities, do Part B.
Part A

Investigation: Effect of Solar UV Radiation on Cells

This investigation is from Ward’s Natural Science, Effects of UV Radiation on Cells 85W3519.¹

Objective

The objective of this investigation is to determine the lethal effect of solar UV radiation on UV-sensitive yeast cells.

Background Information

Ultraviolet (UV) radiation is a form of light energy just beyond the range of human vision. UV radiation is natural in solar radiation and reaches the surface of the Earth in various intensities depending on angle of light, depth of atmosphere, and obstacles such as clouds, dust, and ozone molecules. Unfortunately, UV light is able to penetrate skin cells. A temporary effect may be a sunburn. A longer-term and much more serious effect can be the disruption of skin cell DNA, which can lead to skin cancer. Many organisms are sensitive to UV light. Some can repair damage to their DNA, others cannot.

Ordinary baker’s yeast, Saccharomyces cerevisiae, is a friendly microorganism that repairs its DNA in many of the same ways that your skin cells do. You can use yeast cells as a model system to do experiments on the effects of solar UV radiation on cells, since the DNA in all cells is a target for UV radiation damage. Because ordinary yeast cells repair DNA damage, they are not very sensitive to UV light. But strains of yeast that have mutations in genes necessary for this repair are UV-sensitive and are easy to study. One such strain, G948-1C, was developed by Dr. John Game at the University of California. It carries three mutant repair genes and is therefore extremely sensitive to solar UV radiation.

In the following experiment you will use this strain of yeast to investigate the solar UV light that can damage DNA and you will explore the UV-absorbing properties of materials that can protect you from it.

Materials

- sterile water
- alcohol wipes
- tape and scissors
- sunlight
- YED agar plate in petri dish
- heavy, opaque paper
- incubator or warm, dark, moist location
- prepared suspension of G948-1C yeast cells in water

¹ Ward’s Natural Science is the exclusive distributor of the kit and investigation Effects of UV Radiation on Cells 85W3519. Reprinted with permission of Kansas State University GENE Program and National Science Foundation.
Procedure

See the Prelaboratory Preparation in the Appendix.

5. Why is a suspension of yeast cells made?

Procedure for Exposing Yeast Cells to Sunlight

1. Swirl to suspend fresh yeast in water.
2. Dilute suspension in 0.9 mL of water.
3. Pour suspension onto YED plate.
4. Tilt and rotate to spread lawn of cells.
5. Cover half of the plate.
6. Expose to the sun.

- Using sterile technique, make a heavy suspension of yeast cells in a small (25-30 mL) volume of sterile water in the jar by gently scraping up the growing culture of G948-1C cells with the blunt end of a toothpick. Wipe the cells onto the inside of the container. Replace cover. Swirl to suspend the cells. Add cells until the suspension looks milky. (Your teacher may have already done this for you.)

- Measure 0.9 mL of sterile water into a small capped tube.

- Add 0.1 mL of the suspension from the jar to the 0.9 mL of water in the tube.

- Pour the contents of the tube onto the YED agar plate.

- Replace the lid of the plate to maintain sterility, and tilt and rotate it to spread the cells in a lawn over the surface of the agar. If there are places the liquid did not cover, use the blunt end of a toothpick to guide the suspension to cover those areas.

- Allow the agar to absorb the liquid for about 10 min, or until the liquid disappears.
- Secure the lid to the bottom of the petri dish using a small piece of tape on the side of the dish. (The plastic lid of the petri dish does not absorb a significant amount of the UV-B found in sunlight, but the tape will.)

- Cover half of the lid with a card, opaque tape, or lightproof envelope.

- Cover part of the exposed area of the lid with a sunscreen or anything else you want to test for its ability to absorb UV.

- Expose the plate to direct sunlight in a sunny outdoor location for 5 to 10 min. Place a paper or card under the plate to show a shadow to help you aim the plate directly at the sun, making sure that the surface of the agar will be perpendicular to the sun’s rays. At this position the shadow will be smallest. While you are exposing your plate, observe the approximate angle of the sun.

  The point in the sky directly overhead is called the zenith. It is useful to measure the angle of the sun from this position. You can estimate this angle by looking at your shadow when you are standing upright (or more accurately from measuring the shadow of a vertical meter stick). If the length of your shadow is equal to your height, then the zenith angle is 45°. When your shadow is longer, the angle is greater and the intensity of UV will be much less. For this reason, the intensity of UV in sunlight is greatest during midday hours and during the summer. At noon on a clear summer day, a two-minute exposure will kill the exposed yeast, but during the school year the time must be increased since the sun is lower in the sky.

- Incubate the plate at 30°C for two days or at room temperature for three days.

**Observations**

Carefully record your observations of any yeast growth over the next three to four days. Remember, you have three possible areas for growth: under the opaque paper, under the sunscreen or test substance, and on the fully exposed area.

6. Predict the response of the yeast to UV light.

**Analysis and Interpretation**

7. Explain your results.

8. How would changing the time of day or day of the year you expose the plate to UV radiation affect your results?

9. Why is it important to hold the plate perpendicular to the sun’s rays for 10 min?

   Check your answers by turning to the Appendix, Section 3: Activity 1.
Part B

Scientific research continues to find explanations for diseases and disorders. In some cases solutions to disorders may be found in the alteration of DNA. Read about gene therapy on pages 511 to 512 in your text. After reading, complete the following questions.

10. Briefly describe three basic types of gene therapy.

11. Carefully examine each of the following diagrams and determine which illustration matches each of the following terms.

- deletion – gene removed
- inversion – gene sequence reversed
- translocation – gene moved to different chromosome
- duplication – gene duplicated in place

![Diagrams of gene sequences showing deletion, inversion, translocation, and duplication]
This exercise is an example of an entire gene being altered. Now you’ll investigate examples of just one nucleotide in the DNA sequence being altered.

12. Using the following normal sequence of DNA nucleotides and the messenger RNA code words in Table 23.1 on page 535 in your text, find the three amino acids that will be linked.

DNA Sequence

mRNA Sequence

Amino acids

13. Determine whether each of the following mutations is a case of substitution, insertion, or deletion. Explain your evidence.

14. Find the amino acid sequence of each mutant.

a. DNA

mRNA

Amino acids

b. DNA

mRNA

Amino acids
In this activity you have learned that conditions in the environment can cause mutations. New technology is helping researchers to identify genomes and begin the incredible task of gene therapy. You will learn more about genetic manipulations in the next activity.

ACTIVITY 2 Genetic Engineering: Human Solutions

What’s wrong with the following sentence?

If you are wearing special sunglasses, then the sky may very well be green. However, under normal circumstances you must either change the word green to blue or you could change the word sky to leaf. You get a clear and accurate message in both cases after the change.

Sometimes errors occur in the genetic code and require correction. To read about how a cell accomplishes these changes, read pages 527 and 528 in your text. When you have finished reading answer the following questions.

1. Explain the “cut and paste” action of certain endonucleases in the cell.

2. Evaluate the significance of Boyer and Cohen’s experiments with E.coli bacteria.

3. If the genes that produce chlorophyll in plants were inserted into the chromosomes of cattle, determine some of the possible advantages of this procedure.

Check your answers by turning to the Appendix, Section 3: Activity 2.

Check your answers by turning to the Appendix, Section 3: Activity 1.
Establishing the correct genetic information necessary to produce a specific protein is essential to genetic engineering. Then the gene can be removed from its original position in the chromosome and added to the DNA of a host cell. Read about this biotechnology on pages 528 and 529 in your text. After you have finished reading, answer the following questions.

4. Describe the growth of biotechnology over the last decade.

5. Using the information found in Table 22.1 on page 529 of your text, analyse the possibilities of using genetic engineering positively.

6. Discuss the implications of companies being able to patent new life-forms produced by biotechnology such as the new, improved mouse.

There is always the possibility of misusing new technology. To learn about some real examples of this, read pages 547 and 549 in your text. When you are finished reading, answer the following questions.

7. Describe the basic principle behind biological warfare.

As you have read, biological warfare is not a new idea. Unfortunately, when combined with modern technology, this type of warfare could conceivably threaten the existence of the human species. Biological warfare is a sad consequence of the collision of science, technology, and society.
Consider this scenario:

Bacteria A is lethal but is quite rare, reproduces slowly, and is sensitive to penicillin.

Bacteria B is not harmful but is very common and reproduces quickly. Bacteria B is also resistant to penicillin.

In a recombinant DNA laboratory, the genes for penicillin resistance and rapid reproduction were identified in Bacteria B and removed and spliced into Bacteria A.

8. Describe the characteristics that may be expected in the new Bacteria A. Which characteristic in the scenario is not genetic? Evaluate the consequences.

9. Using a hypothetical E.coli chromosome that contains a disease-causing gene, create a simulation on paper that demonstrates the use of restriction enzymes and ligases that would render this microbe harmless.

Check your answers by turning to the Appendix, Section 3: Activity 2.

While there are real fears over the control mechanisms for gene engineering, this biotechnology offers a real solution to many genetic problems. Will humans use this knowledge wisely?
Sometimes humans get a little carried away in trying to solve problems. “An ounce of prevention is worth more than a pound of cure.” This axiom reveals much in disease research. Being able to prevent a genetic disorder from being expressed may certainly be worth more than all the drugs used to curb the effect of that condition.

In this last activity you will learn about two diseases that plague humans today. The first is really a group of related diseases known as cancer. The second disease likewise is a group of disorders associated with the immune system (AIDS). Read pages 544 to 547 in your text and answer the following questions.

1. Complete Review questions 11 to 13 found on page 547 in your text.
2. Discuss the two lines of evidence that indicate that cancer results from mutations in the genetic code.

Check your answers by turning to the Appendix, Section 3: Activity 3.

The second disease you will study is known as AIDS – Acquired Immune Deficiency Syndrome. To gain more practical knowledge in disease research, perform the Case Study: Human Immunodeficiency Virus as found on pages 541 to 544 in your text.
Investigation: Human Immunodeficiency Virus

Objective
Investigate the genetic properties of HIV.

Procedure
Complete steps 1 to 3.

Observations
3. Complete Procedure questions a to j on pages 541 to 543.

Analysis and Interpretation
4. Complete Application questions 1 to 8 on page 544 in your text.

Check your answers by turning to the Appendix, Section 3: Activity 3.

By now you may think that many of the world’s serious problems have a basis in genetics. You’re right, but look on the positive side. You know more about it now than when you began studying this module.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

In this section you have learned about technological advances that have opened a new world of research. As astronomers look to the heavens for answers about the origins and destiny of the universe, biologists can now look to the genetic code for answers about the origins and destiny of life.

Check out page 92 in the January 1994 issue of Discover magazine for some discoveries of human genes and diseases.
1. Complete the following crossword puzzle.

<table>
<thead>
<tr>
<th>Across</th>
<th>Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>b. DNA that can move along a chromosome</td>
<td>a. sexual reproduction where genetic material is exchanged</td>
</tr>
<tr>
<td>e. a normal bacteria found in the human gut</td>
<td>b. procedures that replace defective genes with normal genes</td>
</tr>
<tr>
<td>h. an enzyme that glues DNA together</td>
<td>c. restriction enzymes</td>
</tr>
<tr>
<td>i. complete genetic code within an organism</td>
<td>d. identical copies</td>
</tr>
<tr>
<td>j. technique for separating DNA in electrical fields</td>
<td>f. uses reverse transcriptase</td>
</tr>
<tr>
<td>k. adding a nucleotide to the sequence in a gene</td>
<td>g. DNA from two different organisms that is united in one</td>
</tr>
<tr>
<td>n. disease-causing agent</td>
<td>l. cancer-causing gene</td>
</tr>
<tr>
<td>p. cancer-causing agent</td>
<td>m. a mutagenic agent that may cause cancer</td>
</tr>
<tr>
<td>q. gene that acts as a switch to turn off segments of DNA</td>
<td>o. a test for cancer-causing agents</td>
</tr>
</tbody>
</table>

Check your answers by turning to the Appendix, Section 3: Extra Help.
2. How is genetic engineering like editing an English essay?
3. What are three cancer-causing agents?
4. Why is the Human Immunodeficiency Virus such a devastating pathogen?

Check your answers by turning to the Appendix, Section 3: Extra Help.

**Enrichment**

Do one or more of the following:

1. Critical-Thinking question 6 on page 515 in your text
2. Critical-Thinking question 3 on page 531 in your text
3. Enrichment Activity question 1 on page 531 in your text
4. Critical-Thinking question 1 on page 552 in your text
5. Critical-Thinking question 3 on page 553 in your text

Check your answers by turning to the Appendix, Section 3: Enrichment.

**Conclusion**

Just like the untimely explosion of the space shuttle Columbia, human disease can rob life from a hope of a better tomorrow. Technology has rebuilt the space shuttle and wisdom should prevent another disaster. Biochemical technology is changing and rebuilding factors that actually control living organisms. Will wisdom prevent further disasters? That question is a hard one to answer, but you now have the knowledge to try.

**Section 3 Assignment: Biochemical Technology**

Review the Evaluation information found in the introductory pages of this module.

It is important to number and clearly identify each page with the following information at the top:

Biology 30 – Module 5   Section 3 Assignment   Page #   Name and ID#

Be sure to write legibly. Leave a wide left margin and number all of your pages.
Carefully read each of the following multiple choice questions and decide which of the choices best completes the statement or answers the question. Each question is worth 1 mark.

1. Retroviruses are unique as genetic entities because they
   A. can transcribe RNA to DNA
   B. can incorporate their genetic material into a host cell’s chromosome
   C. have DNA that is not a double helix
   D. can bring about translocation in their host cells

2. DNA segments that can enter a genome at many different points but that remain fixed once they do enter are known as
   A. transposons
   B. insertion sequences
   C. incorporated mutagens
   D. cofactors

3. The natural function of a restriction enzyme is to
   A. cut up foreign DNA
   B. remove sections from the mRNA transcript
   C. remove sections from the tRNA transcript
   D. facilitate mRNA formation from nucleotides

4. Insertion of a foreign DNA sequence into an E.coli plasmid is done in order to _____________ after several generations.
   A. produce a cloned gene that can be harvested
   B. remove the ability to transcribe the foreign gene
   C. bring about bacterial transformation
   D. form a mutant, disabled strain of E.coli

5. A restriction enzyme acts upon the following DNA segment by cleaving both strands between adjacent thymine and cytosine nucleotides.
   \[ ...TCGCGA... \]
   \[ ...AGCGCT... \]

   Which of the following pairs of sequences indicates the sticky ends that are formed?
   A. \[ ...AGCGC CGCGA... \]
   B. \[ ...TCGC TCGG... \]
   C. \[ ...T A... \]
   D. \[ ...GA AG... \]
Use the following information to answer question 6.

If the genetic code is to be transmitted accurately from one generation to the next, then DNA replication must be accurate. If there is a mistake in the process, then the sequence of nitrogenous bases in the DNA may be altered. This is a mutation. Mutations are rare, random events, but they do occur. Since every cell in an organism contains a full complement of genetic material, a mutation can occur in any cell.

6. a. Describe three different types of mutations and indicate the general agents of mutation. (3 marks)

b. Provide two examples of technology that is used to manipulate genes and correct disorders. (2 marks)

7. a. Compare DNA replication to DNA transcription. Illustrate your answer. (4 marks)

b. Distinguish between transcription and translation. Illustrate your answer. (4 marks)

c. Which kinds of genes are transcribed but not translated? Explain your answer. (2 marks)

Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

**Science Skills**

- [ ] A. Initiating
- [ ] B. Collecting
- [ ] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

**MODULE SUMMARY**

In this module you have learned that the genetic code is a complicated language of nucleic acids, which is organized into codons, genes, and chromosomes.

Interactions with the environment allow the expression of the genetic information in the form of observable traits. Errors in expression occur and current technology is striving to correct those mistakes. The challenge of the future lies in wisely using this knowledge.
Molecular Heredity begins with DNA

replication makes New DNA
if copied perfectly may mutate
leads to passing changes to
Mitosis New Generations

transcription passes code to mRNA
leaves nucleus for cytoplasm where
Ribosomes and tRNA
assemble amino acids to make Protein

To ensure that all of your work has been completed in a satisfactory manner, check off the items in the following list:

- Section 1 Assignment has been completed.
- Section 2 Assignment has been completed.
- Section 3 Assignment has been completed.
- Your responses are organized and neat, with room for teacher comments.
- All your response pages are numbered consecutively and identified with this heading.
Appendix

Glossary

falsify: to experimentally prove or declare an hypothesis to be false

heredity: the inheritance of traits and characteristics from ancestors

gene: one full set of chromosomes that contain all the genetic information for a cell

verify: to experimentally prove or declare an hypothesis to be true

Note: The crossword puzzles found in the Extra Help of Sections 1 and 3 provide the definitions for many important terms in this module.

Suggested Answers

Section 1: Activity 1

1. Genes are units of DNA that produce and influence the physical traits of an organism. Genes are linked together to form chromosomes just like beads can be linked together to form a necklace.

2. Some examples of technology that have made the study of genetics possible are:
   - the light microscope (identification of chromosomes)
   - the electron microscope (the structure of chromosomes)
   - X-ray diffraction (the location of genes on chromosomes)
   - gel electrophoresis (the properties of genes and chromosomes)

3. The study of cells (cytology) and their behaviour has enabled geneticists to observe the reproductive behaviour of these individual units of life. The division of the nucleus during mitosis and meiosis has opened the door to understanding how traits are transmitted from parents to offspring. Hence, the study of structure has made the study of function possible.

4. Remember to use what you learned in the previous modules as well.

   - Chromosomes carry genes.
   - Homologous chromosomes segregate during meiosis.
5. As he studied eye colour in Drosophila, Morgan found a white-eyed male among many red-eyed offspring. When mating occurred, the results conformed to Mendelian probabilities. The F_1 generation produced from hybrid parents showed a 3:1 ratio (red-eyed:white-eyed). However, all the females had red eyes, while amongst male fruit flies half had red eyes and half had white. All of the white-eyed offspring were male. Further investigation suggested that the gene for eye colour was found on a sex chromosome and was linked to the sex of each fly.

6. Autosomes are chromosomes that are common to males and females. Sex chromosomes determine gender and in females are homologous (XX), but in males are not (XY).

7. **Review question 1. (a):** Because the gene for hemophilia is a sex-linked recessive gene, hemophilic offspring can be produced by two normal parents. If the mother is heterozygous, and contributes the h gene, 1/2 of the male children will be hemophilic. Here is what the cross would look like.

```
<table>
<thead>
<tr>
<th>Normal female carrying one recessive allele</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal male</td>
</tr>
<tr>
<td>X^H</td>
</tr>
<tr>
<td>Y</td>
</tr>
</tbody>
</table>
```

1/2 F_1 males are hemophilic.

**Review question 1. (b):** No female offspring of normal parents can be hemophilic because the father can only contribute a dominant gene to the female offspring. A Punnett square would show the cross like this.

```
<table>
<thead>
<tr>
<th>Normal female carrying one recessive allele</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal male</td>
</tr>
<tr>
<td>X^H</td>
</tr>
<tr>
<td>Y</td>
</tr>
</tbody>
</table>
```

All of these F_1 females are normal even though they carry a gene for hemophilia.
• **Review question 2. (a):** Cross $X^wX^w$ with $X^wY$. You should get this result.

<table>
<thead>
<tr>
<th>$F_1$ ratio</th>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$X^wX^w$</td>
<td>normal, female</td>
</tr>
<tr>
<td>1</td>
<td>$X^wX^w$</td>
<td>small notches, female</td>
</tr>
<tr>
<td>1</td>
<td>$X^wY$</td>
<td>normal, male</td>
</tr>
<tr>
<td>1</td>
<td>$X^wY$</td>
<td>dead, male</td>
</tr>
</tbody>
</table>

• **Review question 2. (b):** The researcher never finds dead females in the $F_1$ generation because no male with the $N$ trait can mate, all such males are dead.

• **Review question 2. (c):** The male would be dead.

• **Review question 3. (a):** Parents $BBVV \times bbvY$

The cross would look like this.

<table>
<thead>
<tr>
<th>$bbvY$ (male)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$bbvY$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$BBVV$ (female)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$BBVV$</td>
</tr>
<tr>
<td>$BbVv$</td>
</tr>
<tr>
<td>$BbVV$</td>
</tr>
<tr>
<td>$BbVv$</td>
</tr>
</tbody>
</table>

Remember that the $B$ or $b$ gene is on an autosome and the $V$ or $v$ gene is sex linked on the $X$ chromosome. No genes of these kinds are on the $Y$ chromosome but the $Y$ chromosome is important to identify males.

• **Review question 3. (b):** $BbVv$ (wild-type female) $\times$ $BbVY$ (wild-type male)

Parents $BbVv \times BbVY$

<table>
<thead>
<tr>
<th>$F_1$ ratio</th>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$BBVV$</td>
<td>wild-type, female</td>
</tr>
<tr>
<td>1</td>
<td>$BBVv$</td>
<td>wild-type, female</td>
</tr>
<tr>
<td>2</td>
<td>$BbVV$</td>
<td>wild-type, female</td>
</tr>
<tr>
<td>2</td>
<td>$BbVv$</td>
<td>wild-type, female</td>
</tr>
<tr>
<td>1</td>
<td>$bbVV$</td>
<td>brown-eyed, female</td>
</tr>
<tr>
<td>1</td>
<td>$bbVv$</td>
<td>brown-eyed, female</td>
</tr>
<tr>
<td>1</td>
<td>$BBvY$</td>
<td>vermilion-eyed, male</td>
</tr>
<tr>
<td>1</td>
<td>$BBvY$</td>
<td>vermilion-eyed, male</td>
</tr>
<tr>
<td>2</td>
<td>$BbVY$</td>
<td>wild-type, male</td>
</tr>
<tr>
<td>2</td>
<td>$BbVY$</td>
<td>wild-type, male</td>
</tr>
<tr>
<td>1</td>
<td>$bbVY$</td>
<td>brown-eyed, male</td>
</tr>
<tr>
<td>1</td>
<td>$bbvY$</td>
<td>brown-eyed, male</td>
</tr>
<tr>
<td>1</td>
<td>$bbvY$</td>
<td>white-eyed, male</td>
</tr>
</tbody>
</table>

Notice that both parents are heterozygous for the $B$ gene and the female parent is also heterozygous for the $V$ gene. Careful scrutiny of the genotypes is necessary to determine each phenotype. Draw a Punnett square.
• **Review question 3. (c):** \( bbVV \) (brown-eyed female) \( \times BbY \) (vermilion-eyed male)

Your cross should look like this:

<table>
<thead>
<tr>
<th>( Bv )</th>
<th>( BbVo )</th>
<th>( BbVv )</th>
<th>( BbVv )</th>
<th>( BbVv )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( BY )</td>
<td>( BbVY )</td>
<td>( BbVY )</td>
<td>( BbVY )</td>
<td>( BbVY )</td>
</tr>
<tr>
<td>( bv )</td>
<td>( bbVv )</td>
<td>( bbVv )</td>
<td>( bbVv )</td>
<td>( bbVv )</td>
</tr>
<tr>
<td>( bY )</td>
<td>( bbVY )</td>
<td>( bbVY )</td>
<td>( bbVY )</td>
<td>( bbVY )</td>
</tr>
</tbody>
</table>

Parents \( bbVV \times BbY \)

<table>
<thead>
<tr>
<th>( F_1 ) ratio</th>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( BbVv )</td>
<td>wild-type, female</td>
</tr>
<tr>
<td>1</td>
<td>( bbVv )</td>
<td>brown-eyed, female</td>
</tr>
<tr>
<td>1</td>
<td>( BbVY )</td>
<td>wild-type, male</td>
</tr>
<tr>
<td>1</td>
<td>( bbVY )</td>
<td>brown-eyed, male</td>
</tr>
</tbody>
</table>

8. The chance of finding a colour-blind person increases with sample size. Normal colour vision will produce these results:

• **Procedure question a:**

<table>
<thead>
<tr>
<th>Plate</th>
<th>Number Identified</th>
<th>Actual Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>3</td>
<td>no number</td>
<td>no number</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

A person who is colour-blind for green will not see number 15 or 16. A person colour-blind for red will not see number 57.

• **Procedure question b:** Generally if your sample size is large enough, more males will show colour blindness than females.

9. **Laboratory Application question 1:** Males and females would show equal frequency. (This is also assuming a large sample size.)

**Laboratory Application question 2:** The mother is \( X^C X^c \) heterozygous. The son inherits the colour-blind gene from the mother. The father contributes the \( Y \) chromosome, which determines maleness.

**Laboratory Application question 3:** For males to acquire diabetes, they must receive two \( dd \) alleles; however, for males to get colour blindness, they only need a single colour-blind allele.
• **Laboratory Application question 4:** For females to get hemophilia, the father would have to carry a hemophilic gene and the mother must carry at least one hemophilic gene. Hemophilia, for females, would be especially serious after puberty. The female reproductive cycle presents many problems which ultimately could result in death. This ensures that the homozygous recessive disorder becomes very rare—these genes will not survive. However, colour blindness presents no such detrimental condition. People who are colour-blind can go on to lead a normal lifestyle.

**Section 1: Activity 2**

1. **gene or allele:** a portion of the chromosome that contains the code for a specific trait; its location on the chromosome or **locus** is the same on each of the homologous chromosomes

2. **genotype:** a representation of the genes or alleles on a chromosome made by using letters; a capital for the dominant form and a lower case for the recessive form

3. **phenotype:** the physical expression of a trait that is most often coded by a pair of alleles found on homologous chromosomes

4. **homozygous:** a genotype where both alleles are the same and result in the same phenotype; e.g., RR or rr

5. **heterozygous:** a genotype where the two alleles are different and create a hybrid condition; e.g., Rr

6. **F₁:** the first filial generation of offspring from a parental cross

7. **homologous:** chromosomes that have the same sequence of genes even though the genotype may vary

8. **F₂:** the second filial generation of offspring produced by crossing F₁ offspring

9. **segregation:** the random separation of homologous chromosome pairs during cell division

10. **dominant:** the gene or allele that determines the trait when genotype is heterozygous

11. **gamete:** reproductive cells formed during meiosis which contain single chromosomes instead of homologous pairs; egg: sperm

12. **recessive:** the gene or allele that is not expressed as a trait unless genotype is homozygous

2. Test crosses help to determine the genotype of one of the parents. If one parent is homozygous recessive, all the gametes produced have recessive alleles. The genotype of the other parent will ultimately then determine the offspring’s phenotype, for example, A? x aa.

   If the offspring are 100% dominant in phenotype, it is likely that the unknown allele is A and all the offspring are hybrids Aa.

   If any of the offspring show the recessive phenotype, then the unknown allele must be a to produce an aa genotype.

Therefore, test crosses are essential in determining the unknown parental genotype. Remember, it is easy to see phenotype.
3. Because each parent donates one chromosome to the offspring, the linkages look like this. If no crossing-over takes place during meiosis of this cell, the linkages will remain intact. This means the genes are close together. Genes whose loci are very close to each other as in this case are less likely to be separated when crossing-over occurs.

4. The F₁ generation will be the same as in the previous question. The subtle difference is that the genes are found at opposite ends of the chromosomes. This helps explain why the gametes produced will have extra recombinations. If crossing-over occurs, then the original linkages will change. However, there is an equal chance of all four combinations occurring in theory. It depends how far apart the genes are on the chromosomes. Unequal ratios suggest specific distances apart.

5. If there is an equal chance of each genotype being produced in the gametes, then the results are as follows:

<table>
<thead>
<tr>
<th>Gametes</th>
<th>Possible Offspring Phenotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB × ab</td>
<td>50% dominant for both traits: wild-type body colour and straight wings</td>
</tr>
<tr>
<td>ab × ab</td>
<td>50% recessive for both traits: black body colour and curved wings</td>
</tr>
</tbody>
</table>

6. If there is an equal chance of each genotype being produced in the gametes, then the results are as follows:

<table>
<thead>
<tr>
<th>Gametes</th>
<th>Possible Offspring Phenotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB × ab</td>
<td>dominant; dominant 25% wild-type body colour and straight wings</td>
</tr>
<tr>
<td>Ab × ab</td>
<td>dominant; recessive 25% wild-type body colour and curved wings</td>
</tr>
<tr>
<td>aB × ab</td>
<td>recessive; dominant 25% black body colour and straight wings</td>
</tr>
<tr>
<td>ab × ab</td>
<td>recessive; recessive 25% black body colour and curved wings</td>
</tr>
</tbody>
</table>

7. If the genes were widely separated the actual and theoretical results would match. The actual results differ from the theoretical because the alleles for body colour and wings are relatively close together. This reduces the chance of these linked genes being separated during crossing-over. Therefore, there will be fewer recombinations than expected and more will have the original parental linkages. Low numbers of recombinations indicate strong linkage.

8. Since the gene marker is usually an allele that produces an observable recessive phenotype, it can be used to trace linkages in the offspring. The location (locus) of other alleles can be identified when linked to these markers. A sign on a road map likewise indicates location and distance.
9. Crossover \( \% = \frac{50}{250} \times 100\% = 20\% \)

Since each crossover percent represents 1 map unit, 20% crossover would mean 20 map units apart.

10. The crossover percentages and map units are as follows.

\[ AB = \frac{225}{1000} \times 100\% = 22.5\% = 22.5 \text{ map units} \]

\[ BC = \frac{165}{1000} \times 100\% = 16.5\% = 16.5 \text{ map units} \]

\[ AC = \frac{60}{1000} \times 100\% = 6.0\% = 6.0 \text{ map units} \]

Therefore, the mapped chromosome would look like this.

11. • Procedure question a: The lower section of the chromatid would show crossing-over, involving the FG section from one chromosome and fg section from the other chromosome pair.

• Procedure question b: E and G are the furthest apart.

• Procedure question c: The \\(^{fg}\) and FG alleles have been exchanged.

• Procedure question d: The distance is 6 map units apart.

• Procedure question e: The distance between E and G is 10 map units.

• Procedure question f: The distance between F and G is 4 units.

12. • Application question 1: E to F = 6 units and E to G = 10 units; therefore, F to G must equal the difference between the two, or 4 units.

• Application question 2:

• Application question 3: By examining the combinations you can see that the distance between genes is as follows:

<table>
<thead>
<tr>
<th></th>
<th>5 units</th>
<th>2 units</th>
<th>1 unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>W ↔ X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W ↔ Y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W ↔ Z</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X ↔ Y</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X ↔ Z</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y ↔ Z</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• Application question 4: Use the gene combinations to find the relative distances between genes. Then construct a gene map. Show the relative positions of each of the genes along the chromosome and indicate distances in gene units.

\[
\begin{align*}
A &\leftrightarrow B & 12 \\
A &\leftrightarrow C & 15 \\
A &\leftrightarrow D & 4 \\
B &\leftrightarrow C & 3 \\
B &\leftrightarrow D & 8 \\
C &\leftrightarrow D & 11 \\
\end{align*}
\]

You could carefully draw a single chromosome.

**Section 1: Follow-up Activities**

**Extra Help**

1. **Parents**

   ![Parents](image)

   **Gametes**

   ![Gametes](image)

   **Punnett square**

   ![Punnett square](image)

   **Genotypes**

   \[
   \begin{array}{c|c|c|c|c}
    & X^c Y & X^c X^c & X^c Y & X^c Y \\
   \hline
   X^c & X^c X^c & X^c X^c & X^c Y & X^c Y \\
   X^c & X^c X^c & X^c X^c & X^c Y & X^c Y \\
   \end{array}
   \]

   **Phenotypes**

   - Normal female (carrier)
   - Colour-blind female
   - Normal male
   - Colour-blind male

2. Genes that are far apart on the chromosome are more likely to be separated from each other during crossing-over. This is illustrated in Figure 21.10 on page 503 of your text. The result is the formation of new gene linkages in the gametes. For example, if the parent linkages were \( AB \) and \( ab \), and these genes were found at either end of the chromosome, one point of crossover would separate the pair.

![Crossover](image)

The new linkages become \( aB \) and \( Ab \). They are considered **recombinants**.
3. a. Wild-type body colour is grey and the allele is located at map location 48.5.
   b. Mutant eye colour is purple and brown and the alleles are at 54.5 and 104.5 respectively.
   c. Normal wings is coded for by three alleles found at 13, 67, and 75.5.
   d. Short legs is the trait produced by the gene at 31 on the chromosome.

4. a. Grey body (48.5) – long legs (31) = 17.5 map units = 17% crossover
   b. Dumpy wings (13) – short feelers (0) = 13 map units = 13% crossover
   c. Curved wings (75.5) – vestigial wings (67) = 8.5 map units = 8.5% crossover

5. | a | SEGREGATION | MALE |
   | A |           |     |
   | b |           |     |
   | c |           |     |
   | d |           |     |
   | e |           |     |
   | f |           |     |
   | g |           |     |
   | h |           |     |
   | i |           |     |
   | j |           |     |
   | k |           |     |
   | l |           |     |
   | m |           |     |
   | n |           |     |
   | o |           |     |
   | p |           |     |
   | q |           |     |
   | r |           |     |
   | s |           |     |
   | t |           |     |
   | u |           |     |

   | A | SEGREGATION | MALE |
   | a |           |     |
   | b |           |     |
   | c |           |     |
   | d |           |     |
   | e |           |     |
   | f |           |     |
   | g |           |     |
   | h |           |     |
   | i |           |     |
   | j |           |     |
   | k |           |     |
   | l |           |     |
   | m |           |     |
   | n |           |     |
   | o |           |     |
   | p |           |     |
   | q |           |     |
   | r |           |     |
   | s |           |     |
   | t |           |     |
   | u |           |     |
Enrichment

1. **Textbook question 2:** Sutton and Boveri observed that chromosomes come in pairs which segregate during meiosis. The chromosomes form new pairs when the egg and sperm unite. The paired chromosomes or homologous chromosomes supported Mendel’s two-factor explanation of inheritance.

Sutton and Boveri knew that the egg was much larger than the sperm, but that the expression of a trait was not tied to it being located in a male or female sex cell. Therefore, some structure in both the sperm cell and the egg cell must determine heredity. Sutton and Boveri deduced that Mendel’s factors (genes) must be located on the chromosomes. The fact that humans have forty-six chromosomes, but thousands of different traits, led Sutton to hypothesize that each chromosome contains many different genes.

Thomas Hunt Morgan discovered that some genes are located on sex chromosomes. From experiments on *Drosophila*, he discovered that females have an XX chromosome pair and males have an XY chromosome pair. Morgan also discovered various mutations in *Drosophila*. He noted that some of the mutations seemed to be linked to other traits. Morgan concluded that the two genes responsible for the traits must be located on the same chromosome. This added support to the theory that the genes were located on chromosomes.

Barbara McClintock believed that genes could exchange position on chromosomes. With the exception of a few new combinations that might occur because of crossing-over, chromosome structure was thought to be fixed. Barbara McClintock interpreted her results of experiments with Indian corn and came to a conclusion that would shatter the traditional view of gene arrangement on chromosomes. McClintock suggested that genes can move to a new position. Her theory was dubbed the “jumping gene theory.”

**Textbook question 3:** $X^wX^w$ (wild-type colour, female) $\times X^wY$ (wild-type colour, male)

<table>
<thead>
<tr>
<th></th>
<th>$X^w$</th>
<th>$X^w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X^w$</td>
<td>$X^wX^w$</td>
<td>$X^wX^w$</td>
</tr>
<tr>
<td>$Y$</td>
<td>$X^wY$</td>
<td>$X^wY$</td>
</tr>
</tbody>
</table>

2 wild-type eye colour females
1 wild-type eye colour male
1 white-eyed male

**Textbook question 4:**

a. Parent 1 is a normal female; Parent 2 is a normal male. Consider though if a normal female carries a single gene for hemophilia; she will not show the disease, but can pass on the gene.

b. There is a 3/4 probability that the child would be normal and a 1/4 probability that it would be hemophilic. The mother must be heterozygous for hemophilia.

c. There is a 1/2 probability that the boy would have hemophilia.

d. Number 4 = $X^wX^w$; Number 5 = $X^wY$. **Note:** The female must carry a hemophilic gene because female Child 7 carries two hemophilic genes, one from each parent.
- Textbook question 5:

For $F_1$ generation:

\[
\begin{array}{c|cc}
 & + & tra \\
\hline
tra & +/tra & tra/tra \\
tra & +/tra & tra/tra \\
\end{array}
\]

For $F_2$ generation:

\[
\begin{array}{c|cc}
 & X+ & X tra \\
\hline
X+ & +/+ & +/tra \\
Y tra & +/tra & tra/tra \\
\end{array}
\]

1/2 of the females are sterile.

The $tra/tra$ gene will cause sterile females; $tra/tra$ males are normal. All females and males are normal.

- Textbook question 8:

\[
\begin{array}{c}
C \xrightarrow{3 \text{ units}} \text{FV} \xrightarrow{11 \text{ units}} B \xrightarrow{5.5 \text{ units}} S \\
C \xrightarrow{5.5 \text{ units}} B \\
C \xrightarrow{3 \text{ units}} \text{FV}
\end{array}
\]

The $Living Textbook$ laser videodisc is available from Optical Data Corporation.

Section 2: Activity 1

1. **Review question 1:** DNA is important to the life of a cell in that it provides the directions that guide the repair of worn or damaged cell parts, and it contains the information that allows the cell to be duplicated, allowing the continuity of life. Most DNA is in chromosomes, but you may have read by now that mitochondria and chloroplasts also contain DNA.

- **Review question 2:** Chromosomes are composed of roughly equal proportions of proteins and nucleic acids.

- **Review question 3:** Nucleotides are the basic components of nucleic acids.

- **Review question 4:** Nucleotides are composed of a ribose sugar, phosphate, and nitrogen bases.

- **Review question 5:** Some scientists erroneously concluded that proteins provided the key to the genetic code because of their complexity when compared with nucleic acids. Because proteins and nucleic acids were found in roughly equal proportions in the chromosomes, it was reasoned that the complicated proteins were logical master molecules. Nucleic acids were thought to be too simple to contain the vast amount of information required to produce a cell.

2. **Procedure question a:** The capsuled cells are more virulent, and they cause death.

- **Procedure question b:** The strain of mice may have been particularly sensitive to contaminants in one of the culture plates. The bacteria may not have caused death. By repeating the experiments, many variables can be checked.
• **Procedure question c:** Heating destroyed or killed the bacteria.

• **Procedure question d:** The mouse would have lived. Even untreated noncapsuled bacteria do not cause death. Look back at the first part of the investigation.

• **Procedure question e:** Cells from the culture medium should have been checked for capsules before being injected. A normal prediction would be that the cell mixture would be harmless because the lethal bacteria had been killed by heating.

3. **Application question 1:** The noncapsuled cells either developed capsules or became deadly or both.

• **Application question 2:** The genetic information of the heat-treated cells was incorporated into the noncapsuled living cells. The genetic material transformed the non-virulent bacteria into virulent bacteria, which also had capsules.

• **Application question 3:** This supported their idea that the DNA entered the noncapsuled cells and transformed them into virulent, capped bacteria. As the noncapsuled bacteria reproduce, their offspring begin to show characteristics not found in the noncapsuled parents. The new cells could be a lethal hybrid.

4. **Textbook question 6:** The co-discoverers of the double-helix model of DNA were James Watson and Francis Crick. They presented their model to the scientific world in 1953. The double helix concept began with the X-ray images produced by Rosalind Franklin.

• **Textbook question 7:** The X-ray diffraction pattern provided a view of the twist in the DNA strand. You can see the x patterns in Figure 22.6 on page 522 in your text.

• **Textbook question 8:** Cytosine pairs with guanine. Thymine pairs with adenine. In early analysis of DNA it was noticed that the concentrations were complementary. The concentration of adenine was the same as thymine and the concentration of guanine was the same as cytosine. This is known as Chargaff’s rule, named after Erwin Chargaff.

5. **Textbook question 9:** Because DNA is capable of self-replication, it is possible to pass the information contained in each of your cells to the cell’s descendants. If DNA were not capable of self-replication, the information would have to be divided and reorganized each time a cell reproduced.

• **Textbook question 10:** The nitrogen bases of DNA and their complementary pairs are guanine-cytosine and adenine-thymine.

• **Textbook question 11:** DNA replication begins with the breaking of the hydrogen bonds between complementary nitrogen bases. This produces two parent strands of DNA. Each parent strand acts as a template for a new DNA molecule. Free nucleotides in the cell attach to their complementary bases on the parent strand. A set of enzymes, called polymerases, fuse the nucleotides together. In this way, two identical strands of DNA are formed from the original strand.

• **Textbook question 12:** The proofreading enzymes that scan the DNA strands to check for errors in the nitrogen base pairings are very important. Errors are occasionally introduced by environmental factors such as radiation or chemicals. If left alone, these errors could be harmful or even fatal. The proofreading enzymes identify the damaged areas, which are then repaired or replaced by other specialized enzymes.

• **Textbook question 13:** Even though you take in DNA of fish and other organisms, you do not incorporate this DNA into your cells. Rather, the DNA is broken down into its component nucleotides by enzymes in the digestive tract. These nucleotides are then used by your cells to make human DNA.

66
6. Proteins are the principal structural and functional molecules in a cell. The variety of proteins comes from the blueprint of DNA found in the nucleus of every cell.

7. DNA is composed of a double strand of nucleotides ravelled into a spiral or helix. When it is unwound it is like a ladder with rails composed of alternating phosphates and deoxyribose sugar molecules. The rungs are made of a purine bonded to a pyrimidine. The sequence of purines (adenine, guanine) and pyrimidines (thymine, cytosine) constitutes the genetic code.

8. A full complement of DNA is two sets of chromosomes that are inherited, one set from the father (male) and one set from the mother (female). DNA replication is essential for the continuity of life. Every DNA molecule is an exact copy of an original.

9. Unzipping of the double helix occurs to expose the nitrogenous bases. Free-floating nucleotides will bind in a very specific pattern to each strand of DNA. Purines must bind to pyrimidines to fit the phosphate-sugar rails and the hydrogen bonds between them must fit – adenine and thymine have two sites to bond, while guanine and cytosine have three sites. This ensures that exactly the right sequence of bases is maintained during replication. Now, the two new DNA molecules are identical and can be distributed to each of the new daughter cells produced in cell division. In this way, the continuity of life is maintained.

10. • **Procedure question a:** Adenine and guanine are larger molecules. They have two ring structures. See Figure 22.5 on page 522 in your text.

• **Procedure question b:** The structure is called a nucleotide.

• **Procedure question c:** Your genetic code will be one of many possibilities depending on how you arrange the bases.

• **Procedure question d:** The code of the complementary strand will be unique too, but is still correct as long as adenine pairs with thymine and guanine pairs with cytosine.

• **Procedure question e:** The strands should be identical. Here is a possibility.

![Diagram of DNA replication](image)

11. • **Application question 1:** The shapes of thymine and guanine are not complementary.

• **Application question 2:** The sequence in the new strand is dictated by the sequence in the original DNA.

• **Application question 3:** The joining of the two large molecules (purine) would cause gaps along the ladder. The rungs joined by the smaller molecules (pyrimidines) would be too short to touch.
• Application question 4: The geometry of the paired bases would prevent bonding, or two bases of inappropriate size would cause the strand to pull apart. The incorrect strand might look like the diagram on the right.

• Application question 5: A genetic code that was once ATA CGC would be altered by removing a sequence of bases. In the next activity you will be able to relate these changes to protein synthesis.

Section 2: Activity 2

1. Proteins act as the major structural molecules in cells. For example, the cell membrane is composed in part of proteins. The contractile function of muscle fibres is a result of the structural proteins found in the cytoplasm. Proteins also act as the primary regulators for chemical reactions in cells. Enzymes allow the cell to perform all of its functions and enzymes are specialized proteins.

2. a. \[b \quad i \quad o \quad l \quad o \quad g \quad y\]
   \[2 \quad 9 \quad 15 \quad 12 \quad 15 \quad 7 \quad 25\]

   b. \[p \quad r \quad o \quad t \quad e \quad i \quad n \quad s\]
   \[16 \quad 18 \quad 15 \quad 20 \quad 5 \quad 9 \quad 14 \quad 19\]

   c. \[g \quad r \quad e \quad a \quad t\]
   \[7 \quad 18 \quad 5 \quad 1 \quad 20\]

3. Any new word could be created by simply changing the sequence of letters. Some examples of this that may correspond to your answers include the following:

   - 12-7-9-2-7-15-25 = Igibgoy
   - 20-9-15-16-18-14-5-18 = Tioprner
   - 5-1-18-7-20 = Eargt

Some of the words may even make sense in English!

4. If the enzyme’s amino acid sequence is changed it will not function in catalyzing the chemical reaction. A change in Enzyme 1 will stop the pathway before it even gets started and the initial reactant will accumulate. A change in Enzyme 2 will prevent the reaction from continuing past Intermediate Metabolite B, so it will build up. A change to Enzyme 3 will not allow the final product to be produced and Intermediate Metabolite C will accumulate.

5. For the reaction pathway to function normally, three genes properly synthesizing three enzymes is required.

6. If one gene produces one protein, then the genetic code in DNA is really the blueprint for the production of all proteins – structural and enzymatic. The entire functioning of the cell is therefore controlled by decoding the DNA and producing proteins. Abnormalities in enzyme function can be traced to mutations in genes. If protein structures could be discovered, then gene sequences could be found. The mysteries of heredity would unravel even more. In reality the work of Watson and Crick was a result of the ingenious experimentation and interpretations of Beadle and Tatum.
The sequence of base pairs in a codon makes the genetic code specific. Does this look like a gene map?

8. DNA  TAC  GGA  TTG  CAG  CAT  ATT(?)
RNA  AUG  CCU  AAC  GUC  GUA  UAA(?)
Amino acid  Methionine  Proline  Asparagine  Valine  Valine  Terminator(?)

Remember the sequence of amino acids in this DNA-RNA sequence can be determined by using the dictionary of mRNA code words. The sequence should end with a terminator codon but doesn’t in the example in Figure 23.4.

9. **Review question 1**: mRNA is similar to DNA in that it is composed of sugar, phosphate, and nitrogen bases. However, mRNA contains ribose sugar, as opposed to deoxyribose sugar in DNA. mRNA also contains the nitrogen base uracil, which replaces the thymine base found in DNA.

**Review question 2**: mRNA might carry a message from the DNA to start synthesizing proteins to fight a bacterial infection; for example, mRNA might carry the message UUU which codes for the amino acid phenylalanine.

10. **Review question 3**: tRNA is the molecule responsible for identifying and collecting amino acids circulating in the cytoplasm. The tRNA binds with the amino acid for which it is specific and delivers it to the mRNA.

**Review question 4**: A codon is a three-nitrogen base code for an amino acid. For example, AAG is the codon that specifies the amino acid lysine. An anticodon is a three-nitrogen base code found in tRNA that pairs with the corresponding codon of mRNA.

**Review question 5**: Transcription and translation are two stages in the production of proteins from the instructions contained in DNA. Transcription is the process by which the sequence of bases, or genetic code, is copied from DNA to a mRNA molecule. Translation is the process by which the instructions on the mRNA molecule are used by ribosomes to synthesize proteins.

**Review question 6**: To gain access to the codon UUG, the anticodon would have to be AAC. Adenine only pairs with uracil, and cytosine only pairs with guanine.

**Review question 7**: Proteins are the building blocks of cells. Cell reactions also depend on enzymes which are a class of proteins. Life could not continue if you were unable to make new cells, or if your metabolism was slowed or stopped because of a lack of enzymes.
11. | Nucleic Acid | Sugar   | Helix  | Size       | Site            | Type             |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td>deoxyribose</td>
<td>double</td>
<td>very large</td>
<td>nucleus</td>
<td>DNA</td>
</tr>
<tr>
<td>RNA</td>
<td>ribose</td>
<td>single</td>
<td>small</td>
<td>nucleus and cytoplasm</td>
<td>mRNA, tRNA, rRNA</td>
</tr>
</tbody>
</table>

12. If codons were made of only one nucleotide, there would not be enough different codons for the available amino acids. Since there are twenty amino acids, there must be at least that many codons to achieve the specificity that the genetic code appears to have. Codons of two nucleotides would only produce sixteen different combinations. Therefore, codons of three nucleotides must exist. With sixty-four possible combinations there are more than enough for all the amino acids. This allows for a certain redundancy (four different codons for the same amino acid) and start (initiator) and stop (terminator) codons.

13. The tail allows the mRNA transcript to survive the enzymes of the cytoplasm for a few hours. This allows the ribosomes a chance to translate the messenger RNA into proteins that can be used in the cell’s metabolism.

14. Each tRNA molecule links with its corresponding amino acid (except for the tRNA with an anticodon that will terminate protein synthesis) in the cytoplasm. This makes the tRNA a translator. It has an anticodon, which is the language of nucleic acids and an amino acid, which is the language of proteins. By matching the anticodon of the tRNA with the codon of the mRNA, a corresponding sequence of amino acids is linked to create a protein that matches the sequence of codons in the gene (DNA).

15. The ribosome is the site of translation and protein synthesis. Amino acids are linked together by peptide bonds in exactly the same sequence as the nucleotide sequence in the gene. Therefore without ribosomes, the cell could not produce proteins. Cells which manufacture a large amount of protein have many ribosomes.

```
DNA – Genetic code is the sequence of nucleotides.

Transcription

RNA – mRNA is a copy of the DNA template.
tRNA is the translator carrying amino acids.
rRNA is the site of translation and protein synthesis.

Translation

Synthesis

Proteins – Chains of amino acids whose specificity is essential to the cell’s metabolism and life in general.
```

16. | Molecule          | Number of Subunits | Sequence of Subunits |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td>11</td>
<td>TAC ACG ATA ACA TCC AAA CAA GTT GGA TTA ATT</td>
</tr>
<tr>
<td>mRNA</td>
<td>11</td>
<td>AUG UGC UAU UGU AGG UUU GUU CAA CCU AUA UAA</td>
</tr>
<tr>
<td>Protein (amino acid sequence)</td>
<td>9</td>
<td>init. cyst tyr cyst arg phen val glu pro asp</td>
</tr>
</tbody>
</table>

17. You acted as the enzymes for transcription and translation, as well as serving the function of the ribosome in protein synthesis.
18. | **Similarities** | **Differences** |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• composed of nucleotides</td>
<td>• T found in DNA and U found in mRNA</td>
</tr>
<tr>
<td>• A, C, G are common bases</td>
<td>• deoxyribose sugar in DNA and ribose sugar in RNA</td>
</tr>
</tbody>
</table>

19. The transcript represents a complementary copy of a genetic code for the synthesis of a specific protein.

20. If the AAA code becomes CAA it will now code for a different amino acid – valine. This will change the protein’s function.

**Section 2: Follow-up Activities**

**Extra Help**

1. Purines are double-ringed bases and pyrimidines are single-ringed bases. They must bond with each other to fit the spacing between the rails (sugar-phosphate) of the double helix. Adenine and thymine form only two hydrogen bonds, while guanine and cytosine will form three hydrogen bonds. Therefore, the obligatory base pairing rule is \( A = T \) and \( G = C \).

2. Since there are 33 base pairs shown in Figure 22.6, there will be 11 codons in this gene.

3. The hydrogen bonds that form the rungs of the double helix ladder must break. This exposes the base pairs to free nucleotides that can bond to form a new rail and rung portion for each helix. The semi-conservative replication process is illustrated for you to review in Figure 22.7 on page 523 in your text.

4. ![DNA replication diagram](image)

5. The terms are listed in order of use: genes, traits, nucleotides, transcription, mRNA, ribosome, translation, tRNA, amino acid, sequence, protein, enzymes

6. ![DNA, mRNA, and amino acids](image)
Enrichment

1. **Textbook question 3**: X-ray diffraction is a technique used to determine the shape of a molecule. The X-ray is directed at the crystallized form of the molecule. The diffracted rays are then trapped by film. The pattern produced reveals the 3-D shape of the molecule. This allowed Watson and Crick to determine that DNA was a double helix, not a single helix, as others, like Linus Pauling had suggested.

2. **Textbook question 7**: DNA will not replicate, or the strand of DNA must be broken for that cell to replicate. Should a number of cells of the body absorb that drug, cell division in all of those cells would be impaired. Consider that growth would stop. This could be used as a herbicide. Could such a drug stop cell division and so affect aging?

3. **Textbook question 4**: A new protein would be produced. The genetic code would be altered and different amino acids would be sequenced along the ribosomes.

4. **Textbook question 6**: The drug will prevent synthesis of protein. It is highly unlikely that the death of one single cell could cause death of the entire organism; however, if the drug could be attached to a carrier molecule that would seek out only certain cells, such as cancerous cells, the possibilities are obvious.

5. **Textbook question 8**:
   - Corporate headquarters resemble the nucleus, the command centre.
   - The master blueprint for the car is the DNA, the genetic code of life.
   - The entire shop area is the cytoplasm, the area of the cell in which work occurs.
   - The supervisor who carries the blueprints is the mRNA which carries the genetic code to the ribosomes.
   - The stockperson is the tRNA which carries amino acids to the ribosomes.
   - The assembly worker is the ribosome, the organelle that assembles proteins.
   - The parts of the automobile are the amino acids, the building blocks of proteins.

Section 3: Activity 1

1. **Review question 8**: Mutations are the effect of changes in the genetic code of an organism. They can be inherited.

   **Review question 9**: Gene mutation can be produced by anything that alters the sequence of bases in DNA such as cosmic rays, X-rays, chemicals, or shortages in specific amino acids.

   **Review question 10**: A developing fetus has billions of cells that are rapidly dividing but each cell is the precursor to all future cells. If the DNA in the cells in a fetus is altered by a mutagenic agent, the mutation will be passed to all future cells.

2. The insertion of some genes into new positions along a chromosome may alter the expression of other genes. This may cause a mutation through change in the DNA sequence.
3. Transposable genes in bacteria allow researchers to study gene splicing, but this may be overshadowed by the development of bacterial genes that are resistant to antibiotics. This increases the incidence of disease-causing bacteria that can infect human beings.

4. Radioactive labels can be attached to DNA and traced. Gel electrophoresis allows the separation of DNA that is embedded in a gel by the use of an electrical field. The banding produced helps to map the DNA and determine the location of specific genes.

---

**Prelaboratory Preparation According to Ward’s Natural Science Establishment, Inc.**

To have a freshly grown culture of yeast cells, you must grow the G948-1C strain on YED growth medium overnight at 30°C, or over 1 to 2 days at room temperature.

1. Make a clean, sterile work space by wiping the table or bench with an alcohol wipe. Select a place free from drafts since most contamination is airborne. Use sterile technique.

2. Open the culture vial.

3. Using the broad end of a sterile toothpick, pick up a small amount of yeast.

4. Replace the lid. Tighten. Store in a refrigerator to keep viable for nine months.

5. Open the YED petri dish just enough so that you can reach into it with the toothpick full of cells.

6. Gently make several streaks of the culture on the surface of the agar. (Remember that you need not be able to see the streaks to have enough to grow into a visible culture overnight.)

7. Close the lid.

8. Incubate the culture overnight at 30°C, or for one to two days at room temperature. (Remember that most microbial cultures should be incubated upside down to prevent condensation from dropping on the colonies.)

9. Just before (or during) class, make a visibly turbid suspension of the cells by scraping up some yeast cells with a cotton swab and wiping them onto the inside of the sterile jar. Add about 25 mL of sterile water (so the jar is about half full). Replace the lid and swirl to mix. If the suspension is not visibly cloudy, add more yeast cells.

10. Swirl the jar to resuspend the cells before removing samples.

5. A suspension of yeast cells is made to cover the surface of the agar plate.

6. The half of the plate exposed to UV radiation should not show any yeast growth. The half that was covered and blocked from UV radiation should have grown a culture of yeast.

7. The UV-sensitive yeast was unable to correct the DNA mutations caused by the mutagen, the UV radiation in sunlight.

8. The greatest effect of UV radiation in Alberta would occur at 12:00 noon on the summer equinox of June 21 when there is the greatest amount of sunlight available.

---

1 Ward’s Natural Science is the exclusive distributor of the kit and investigation Effects of UV Radiation on Cells 85W3519. Reprinted with permission of Kansas State University GENE Program and National Science Foundation.
9. This technique ensures that the plate receives the greatest amount of UV radiation possible at that time of day. Otherwise, you may observe limited yeast growth even when exposed to UV radiation.

10. **Gene insertion** is a type of therapy where a missing gene is added to a chromosome. **Gene modification** involves use of a chemical to modify or recode a defective gene. **Gene surgery** is a technique where a defective gene is removed and replaced with a normal gene.

11. a. gene inversion  
   b. gene duplication  
   c. gene deletion  
   d. gene translocation

12. First convert the DNA sequence into mRNA codons. It may help you to split the DNA code into threes. Then go from mRNA to the amino acids.

<table>
<thead>
<tr>
<th>DNA</th>
<th>CGA</th>
<th>ACC</th>
<th>CGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>mRNA</td>
<td>GCU</td>
<td>UGG</td>
<td>GCU</td>
</tr>
<tr>
<td>Amino acids</td>
<td>Alanine</td>
<td>Tryptophan</td>
<td>Alanine</td>
</tr>
</tbody>
</table>

13. a. is a case of insertion. An extra C has been added.  
b. is a case of deletion. G is removed.  
c. is a case of substitution. A C has replaced G in the first triplet.

14. a. Insertion of extra C

<table>
<thead>
<tr>
<th>DNA</th>
<th>CCG</th>
<th>AAC</th>
<th>CCG</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>mRNA</td>
<td>GGC</td>
<td>UUG</td>
<td>GGC</td>
<td></td>
</tr>
<tr>
<td>Amino acids</td>
<td>Glycine</td>
<td>Leucine</td>
<td>Glycine</td>
<td></td>
</tr>
</tbody>
</table>

b. Deletion of G

<table>
<thead>
<tr>
<th>DNA</th>
<th>CAA</th>
<th>CCC</th>
<th>GA</th>
</tr>
</thead>
<tbody>
<tr>
<td>mRNA</td>
<td>GUU</td>
<td>GGG</td>
<td>No mRNA</td>
</tr>
<tr>
<td>Amino acids</td>
<td>Valine</td>
<td>Glycine</td>
<td>No amino acid</td>
</tr>
</tbody>
</table>

c. Substitution of G with C

<table>
<thead>
<tr>
<th>DNA</th>
<th>CCA</th>
<th>ACC</th>
<th>CGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>mRNA</td>
<td>GGU</td>
<td>UGG</td>
<td>GCU</td>
</tr>
<tr>
<td>Amino acids</td>
<td>Glycine</td>
<td>Tryptophan</td>
<td>Alanine</td>
</tr>
</tbody>
</table>
1. Endonucleases are restriction enzymes that break the bonds between nucleotides and "cut" the strand of DNA. Ligase enzymes form bonds between nucleotides and "glue" DNA segments together.

2. These experiments were the first to incorporate the "cut and paste" mechanism of endonucleases in an organism where foreign DNA was placed into the chromosome instead of removed. This has enormous implications – recombinant DNA can synthesize proteins foreign to the bacterium. There are immense possibilities for good, but some possibilities may prove very dangerous.

3. This would provide the animal with the opportunity to produce its own food.

4. Human insulin produced by bacteria was first marketed in 1983. Since that time biotechnology has grown to account for 40% of the pharmaceutical industry (1995) and may reach 70% by the year 2000.

5. From the chart it becomes apparent that a number of human disorders could be corrected or remediated. For example, both anemia and high blood pressure could be held in check by regular injections of recombinant DNA-produced atrial natriuretic factor (ANF) and erythropoietin. Also, cancers and heart attacks could be thwarted in similar fashion.

6. There are many ways that biotechnology could improve the quality of life on Earth. Unfortunately leaving the decision-making process open to anyone may prevent the use of biotechnology for these beneficial processes. Economics may drive companies to use this knowledge in a way that dominates society or unfairly gives power to a small group. Biological warfare is a serious threat to human safety.

7. The underlying principle is the use of living organisms to produce disease and probable death. While these toxic microbes may not be produced by genetic engineering, they just as easily might be created for that purpose.

8. The new Bacteria A will be lethal, reproduce rapidly, and be resistant to penicillin. Rare and common are not genetic traits. The new Bacteria A may become common when helped by its new traits.

9. Your simulation should include the following basic elements.

```
Genes
A
B
C
D
E
F
G

Using scissors (restriction enzyme) cut gene D out from the chromosome.

Using a glue stick (ligase) paste the chromosomes back together.

E. coli chromosome Gene D is disease causing (penicillin resistant).

New E. coli that is not penicillin-resistant (non-toxic.)
```
Section 3: Activity 3

1. • Review question 11: Oncogenes are cancer-causing genes. They stimulate cell division possibly by inhibiting or suppressing genes that prevent cell division.

• Review question 12: As you studied in a previous assignment question, the Ames test identifies cancer-causing agents by their ability to cause mutation in a DNA sequence.

• Review question 13: Regulator genes direct the synthesis of proteins that inhibit or suppress structural genes.

2. Cancer cells display base substitution which alters the triplet codon sequencing necessary for normal gene functioning. Thus, the switch for cell division is left open and a normal cell becomes cancerous. Also, many mutagens (which alter genetic codes) are carcinogenic (cancer-causing). It would appear that these agents affect the same region of the chromosome where the switch for cell division is found. Many sites for oncogenes have been identified in normal cells.

3. • Procedure question a: No, the geometry of the HIV is not compatible with that of the binding sites on muscle and skin cells.

• Procedure question b: The binding sites of the skin will not allow the attachment of HIV.

• Procedure question c: The presence of the viral coat may be detected and identified.

• Procedure question d: It reverses the message; HIV RNA acts as a template for the synthesis of DNA.

• Procedure question e: The viral DNA is also duplicated.

• Procedure question f: The segment containing the HIV has not been activated for protein synthesis. Once it is activated, the segment of DNA that carries HIV genes directs cell ribosomes to construct HIV protein coats. The cell then becomes an HIV protein coat factory.

• Procedure question g: The helper T cells hide the virus.

• Procedure question h: Without a proper, functioning immune system, the body becomes susceptible to many other infections.
• **Procedure question i:** The severe combined immunodeficiency syndrome is not acquired, but due to a genetic mistake prior to birth. HIV is a viral infection.

• **Procedure question j:** Each different shape requires new antibodies with a specific geometry.

4. **Application question 1:** Certain parts of the world have a much higher incidence of HIV, such as parts of Africa, West Indies, and even large cities like London, England.

**Application question 2:** RNA transcribes to DNA, a reversal of normal transcription sequence which goes from DNA to RNA.

**Application question 3:** No, to date no such indication exists.

**Application question 4:** No, to date no such indication exists.

**Application question 5:** Yes, blood is often collected from the end of a needle. If the needle is not sterilized, the infection could be spread. Dentists face the same problems, but it should be noted that strict guidelines for sterilization are mandated.

**Application question 6:** The symptoms are only manifest once many cells have become infected and the helper T cells actively begin making HIV protein coats.

**Application question 7:** This question requires scientific information; it cannot be solved by only using scientific thinking. It is a societal question involving morals, ethics, and laws.

**Application question 8:** This question also requires scientific information. The answer may have social and legal consequences. Do you recall the Module Overview?

**Section 3: Follow-up Activities**

Extra Help

1. 

```
C T R A N S P O S O N S C
H N E C O L I J U T L
H R U R T O
L I G A S E G E N O M E N
V P A C R E
Y E L E C T R O P H O R E S I S
I M
```

```
I N S E R T I O N O B R
N N I A C N D
O A I
```

```
P A T H O G E N A
M E T T
```

```
P C A R C I N O G E N I
S R E G U L A T O R N
```
2. Genetic engineering involves the cutting of DNA by restriction enzymes. This removes various portions from the genetic code. These may be inserted at new positions or discarded. Ligases paste pieces of DNA together in new sequences. Editing an essay also involves a degree of cutting, moving, discarding, and pasting information back together.

3. Carcinogenic agents include certain chemicals (benzene), X-rays, and UV radiation from the sun.

4. The devastation created by HIV is a result of the virus directly attacking the immune system. It targets the T4 lymphocytes which act as guards against invading pathogens. The Acquired Immune Deficiency Syndrome that develops makes an individual incapable of defeating pathogens that would otherwise be easily removed. Persons with AIDS have their immune system weakened so badly that other simple infections become serious and life threatening.

Enrichment

1. **Critical-Thinking question 6**: You may form an opinion on the basis of what you know and what you think is right. Risks have to be weighed against potential benefits. Science won’t have all the answers.

2. **Critical-Thinking question 3**: There are many sides to this question and at least two divergent types of arguments. Each opinion can be supported. Individuals who do not believe in animal testing will indicate that humans do not hold a superior position in the biosphere. Humans have no right to exploit nature. Individuals who support animal testing will indicate that direct human testing creates problems. Animal testing is preferred to human testing.

3. **Enrichment Activity question 1**: You may be able to convince your dentist to expose a bag of bean seeds to X-rays for a few seconds. Another alternative would be to expose the seeds to strong UV light such as used by some barbers to sterilize instruments. Using bean seeds will allow rapid germination. Soak the seeds overnight and keep them in a moist cloth or paper towel in a jar. The control group should not be irradiated, but three other jars with about twenty seeds in each could be radiated with different levels of radiation. Measure the growth rate for about ten days after radiation.

4. **Critical-Thinking question 1**: Some scientists may be motivated by a desire for knowledge while others may seek profit. Most are likely in between. Neither is inherently good or bad. A basic model could be that something is good if it benefits humans or reduces suffering. Regulation and profit are not part of the equation in all cases. Sometimes profit will motivate research and stringent regulation may inhibit research. Some balance is necessary.

5. **Critical-Thinking question 3**: The answer to this question is found not within the discipline of science, but that of ethics. Many people currently wonder if the genetically altered species or strains might not have an unfair advantage. Only certain gene combinations are possible in nature. Recombinant DNA technology, by placing plant and animal genes in bacteria, or vice versa, has far exceeded the realm of nature’s capabilities. Should new forms be released into the environment? This is a difficult question with no simple answer. Risks and benefits have to be known as well as short and long-term consequences.
DNA Symbols