

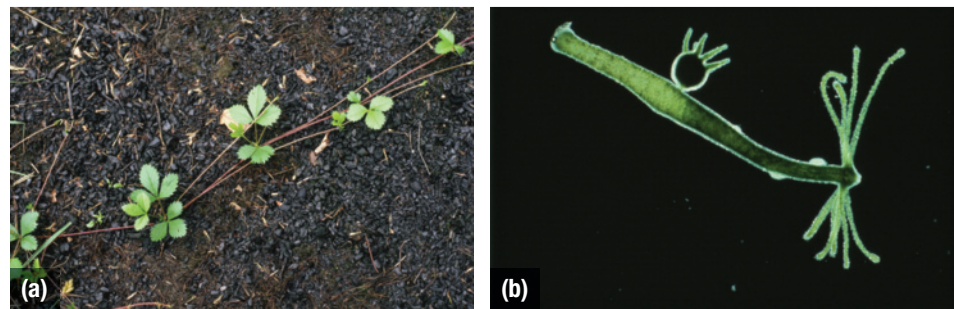
# Asexual Reproduction: Copies and Clones

Asexual reproduction is common in nature. Many organisms reproduce asexually for at least part of their life cycle. Asexual reproduction is the most common form of reproduction among unicellular organisms and is also widespread among many multicellular groups—particularly plants and fungi. Many aquatic and terrestrial invertebrates undergo asexual reproduction, but it is rare among vertebrates.

## Modes of Asexual Reproduction

Asexual reproduction can be both advantageous and practical. Recall from Grade 10 that many plants produce asexually by putting out roots or shoots that develop into new plants. Imagine that a small plant seed—from a strawberry, for example—is blown or carried onto a large patch of bare ground. The seed germinates and begins to grow, and the plant is soon ready to reproduce. Instead of producing flowers, it starts sending out runners (**Figure 1(a)**). These above-ground stems, produced by cell division, quickly extend and develop into new plants. These new young plants in turn grow and begin sending out their own runners. In a relatively short time, many new individual plants quickly spread out and occupy their new environment—a biological success story!

Budding is one type of asexual reproduction in which a new individual develops from an outgrowth on the body of an organism. The hydra, a simple multicellular animal related to the jellyfish, can reproduce asexually by budding (**Figure 1(b)**). When growing conditions are favourable, hydra grow one or more extensions on the sides of their bodies. When they are sufficiently large, these “buds” detach and begin living freely as new, genetically identical individuals.



**Figure 1** Many plants, (a) such as this strawberry, and animals, (b) such as the hydra, are capable of asexual reproduction, producing offspring from the direct outgrowth of their body.



**Figure 2** Female aphids can reproduce asexually, giving live birth to genetically identical female offspring.

Not all asexual reproduction involves the direct outward growth of new individuals from the body of the parent. A fascinating and dramatic example is that of aphids—a group of more than 4000 species of small insects that feed on plants. Female aphids give birth to female offspring (**Figure 2**). These new females are able to start giving birth to more females when they are only a few days old. Since all the new individuals are females, the number of aphids can skyrocket over the course of a few weeks. One species was documented as having produced 41 generations of offspring in a single year!

These numbers are staggering. Beginning in the spring, a female of this species and her descendants are capable of producing a population of over a trillion individuals by late fall. In aphids and many other species, hormonal changes that occur in autumn cause the females to begin giving birth to males as well as females. These aphids then reproduce sexually—providing an opportunity for genetic diversity.

All species of fungi are thought to be capable of asexual reproduction. In fungi, asexual reproduction usually results from **fragmentation**—a process in which parts of the growing mass of fungi simply break off and continue to grow independently.

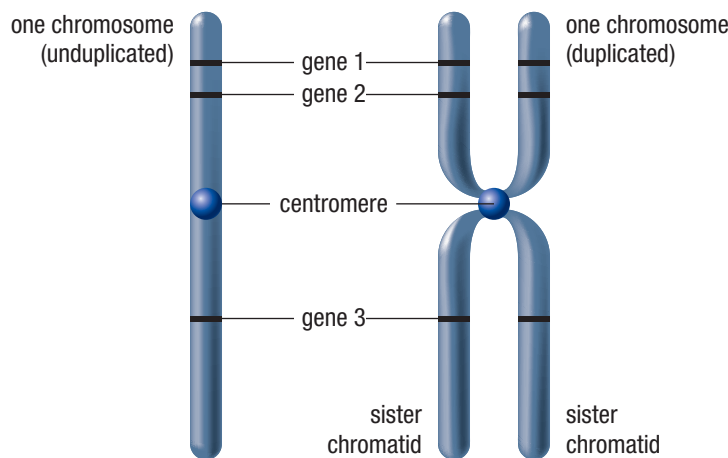
While the frequency and patterns of asexual reproduction are highly variable from species to species, at the cellular level, they usually share one key process—mitosis.

## Cell Division

As you may recall from Grade 10, cell division consists of mitosis and cytokinesis—two of the stages of the cell cycle. **Mitosis** is the stage of the cell cycle during which the genetic material in the nucleus of a eukaryotic cell is divided equally into two new nuclei. The rest of the cell divides during cytokinesis. Some scientists use the term “mitosis” to include both nuclear division and cytokinesis.

The third stage of the cell cycle, during which cells are between cell divisions, is called **interphase**. During interphase, the cell grows and carries out its normal functions. The chromosomes in the nucleus form a mass of thread-like structures called **chromatin**, which are composed of DNA and proteins. When in the form of chromatin, the chromosomes are long, thin strands dispersed throughout the nucleus.

The replication of chromosomes during interphase results in pairs of sister chromatids, each containing exactly the same genes at the same loci. Each original chromosome and its duplicate remain attached by a structure called the centromere. While attached, they are referred to as **sister chromatids**. In Section 4.1, you read that each chromosome contains large numbers of genes at specific loci. During the time that sister chromatids remain attached to each other, they are considered to be one chromosome (**Figure 3**).



**Figure 3** A doubled chromosome is composed of two identical sister chromatids held together at the centromere. Each sister chromatid contains exact copies of the same genes.

As you review the phases of mitosis, you may notice that all chromosomes behave in the same way, with every cell getting a copy of every chromosome. As you will soon learn, this is not true during sex cell formation, when chromosomes are arranged in pairs and sorted accordingly.

Almost all of the heritable information in a cell is carried on chromosomes contained in the nucleus. Sister chromatids carry identical copies of this information, so cells receiving identical sister chromatids also receive identical genetic information. In rare cases, if cells do not receive identical copies of sister chromatids, then they will not receive the same information and will differ genetically from each other.

**fragmentation** a method of asexual reproduction in which a piece or body fragment of the parent organism develops into a mature individual

**mitosis** the process by which a eukaryotic cell divides the genetic material in its nucleus into two new identical nuclei

**interphase** the portion of the cell cycle between mitotic divisions when the genetic material (in the form of chromatin) is duplicated

**chromatin** the tangled strands of DNA and protein within a eukaryotic nucleus

**sister chromatid** the identical copy of a single chromosome that remains attached to the original chromosome at the centromere

### LEARNING TIP

#### Chromosome Composition

An unduplicated chromosome is made up of a single DNA molecule and its associated proteins.

## Prophase

Prophase is the first phase of mitosis (**Figure 4**). During prophase I the chromosomes begin to shorten and thicken and become visible under a microscope. In animal cells, small protein bodies in the cytoplasm called centrioles separate and move to opposite poles of the cell. Centrioles are involved in the formation and organization of spindle fibres, which attach to the chromosomes during cell division. The centromere helps anchor the chromosomes to the spindle fibres. Most plant and fungi cells lack centrioles but still produce a similar set of spindle fibres.

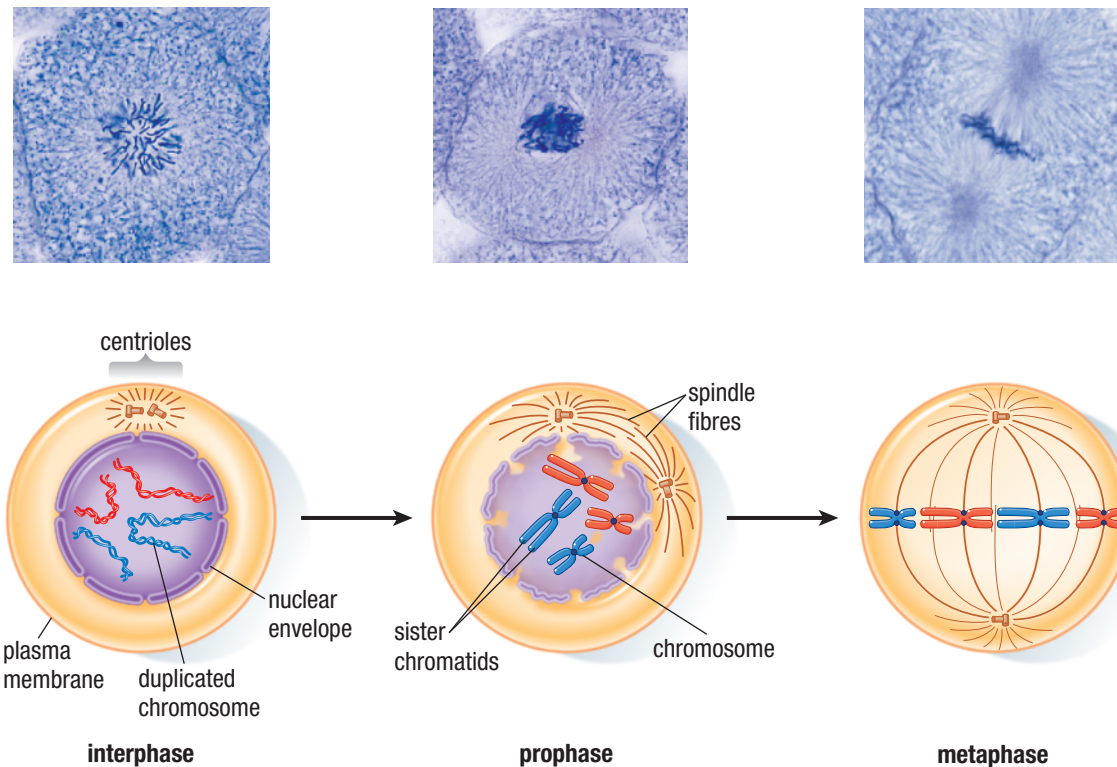
During prophase, the nuclear membrane starts to dissolve. This will eventually allow the chromosomes to separate into the two new daughter cells.

## Metaphase

The second phase of mitosis is metaphase. During metaphase, the spindle fibres begin moving and aligning the chromosomes. Each chromosome, composed of sister chromatids, is pulled toward the centre of the cell, where its centromere becomes aligned across the middle, or equator, of the cell.

## Anaphase

The third phase of mitosis is anaphase. The centromeres divide, and the sister chromatids, now referred to as chromosomes, move to opposite poles of the cell. The chromosomes are being pulled by their centromeres, resulting in a distinctive pattern with the ends of the chromosomes trailing behind. If mitosis proceeds correctly, the same number and type of chromosomes will be found at each pole of the cell.



**Figure 4** Mitotic cell division in an animal cell (diagram continues onto next page)

## Telophase

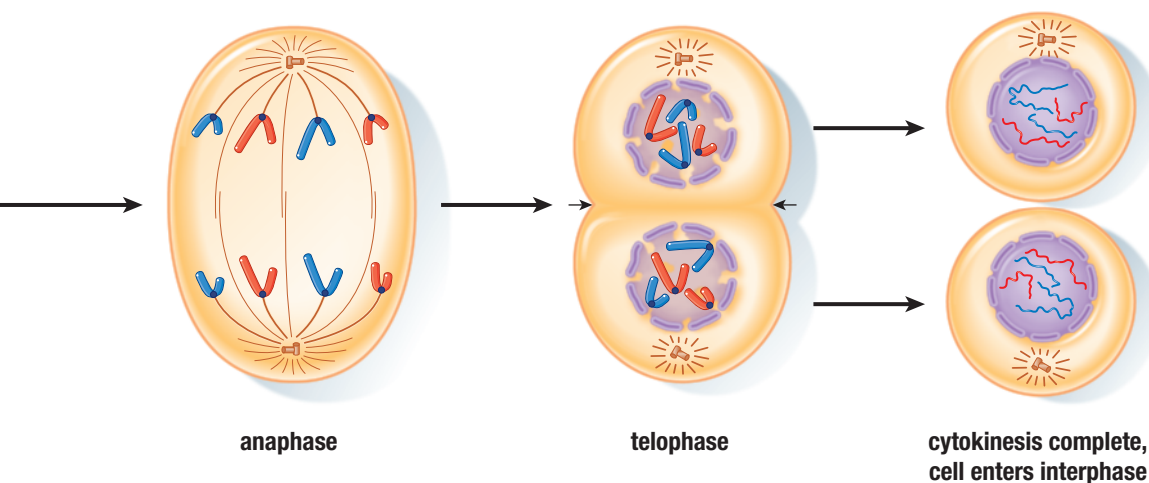
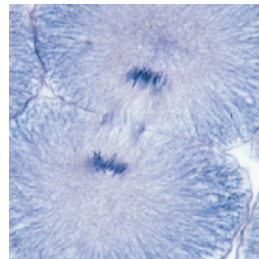
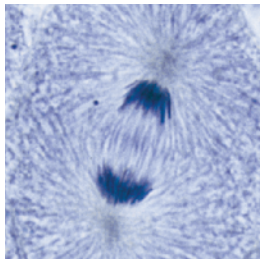
The last phase of mitosis is telophase. Here, chromosomes reach the opposite poles of the cell and begin to unwind. As they do so, the spindle fibres dissolve and nuclear membranes form around the chromosomes. The result is two daughter nuclei.

## Cytokinesis

Mitosis is followed immediately by **cytokinesis**, the stage of the cell cycle when the cytoplasm of a eukaryotic cell is divided to form two new cells. Although the nucleus is divided during mitosis, the division of the cell content into two new daughter cells occurs during cytokinesis. Hence, cell division occurs in two stages—mitosis and cytokinesis.

In many protists, fungi, and animal cells, a furrow develops, pinching off the cell into two parts. In plant cells, vesicles produced by Golgi apparatus begin to gather on both sides of the cell equator. These vesicles then fuse, and their contents begin to form a cell plate between the daughter nuclei. The cell plate becomes the cell walls of the two new daughter cells, while the membranes of the Golgi vesicles unite to form new cell membranes. In both plant and animal cell cytokinesis, separation occurs at the midpoint along the original spindle fibres. In addition to separating the two new nuclei, cytokinesis separates the other organelles approximately equally. During the growth stage of the cell cycle, additional copies of organelles are formed.

**cytokinesis** the process in which a eukaryotic cell divides its cytoplasm into two new daughter cells





## Cloning—Does It Pay to Copy?

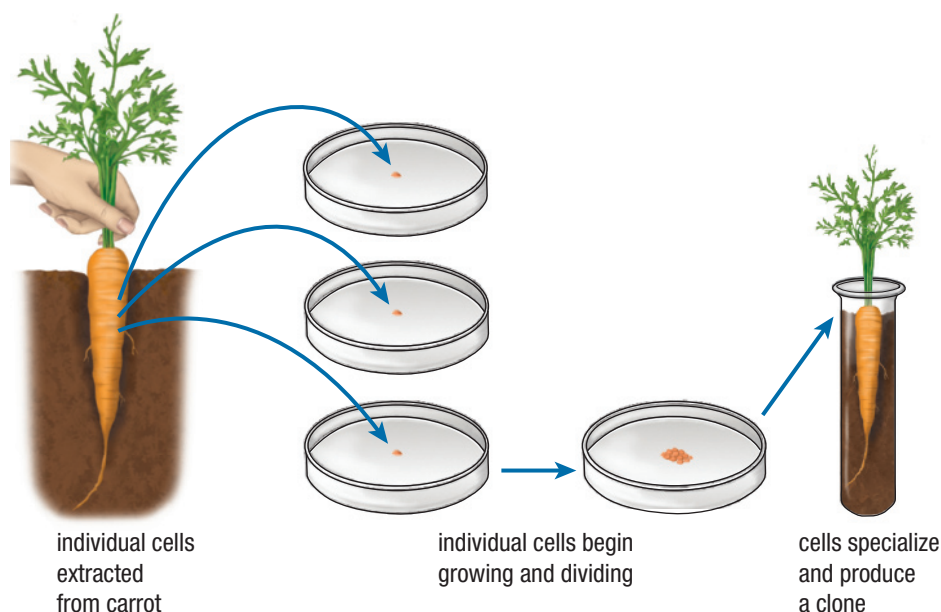
**cloning** the process of producing one individual that is genetically identical to another, using a single cell or tissue

**biotechnology** the use and modification of organisms for applications in engineering, industry, and medicine

In nature, many organisms reproduce asexually by mitotic cell division. The offspring, which are genetically identical to the parent, are referred to as clones. **Cloning** is the process of forming identical offspring from a single cell or tissue. Individuals produced by mitotic cell division are natural clones. However, cloning is not limited to natural processes. **Biotechnology** is a field of biology that involves the use of living things in engineering, industry, and medicine. Biotechnology includes cloning plants for use in agriculture. For example, plants with predictable traits could be cloned to produce larger crop yields. Biotechnology has many applications that are used to benefit society, but it also has potentially negative implications.

### Plant Cloning

In 1958, plant biologist Frederick Steward announced his success in cloning a plant from a single carrot cell (**Figure 5**). The event was remarkable because Steward was able to clone a carrot plant beginning with mature, specialized cells from another carrot. By growing individual root cells in a nutrient-rich medium containing some plant hormones, Steward was able to get the cells to return to an undifferentiated state (lacking any resemblance to carrot tissues). The cells then restarted the process of growth, specialization, and development into new plants.



**Figure 5** Plant cloning from a single cell enables growers to produce very large numbers of new plants from a single individual.

Today, this technique is commonly used to produce strains of plants with identical characteristics. Plant tissue cloning techniques are now widely used commercially. Valuable ornamental plants such as orchids and petunias can be cloned, as well as some valuable agricultural plants, including bananas and grapes. Other plant families, including important grasses and legumes, do not respond well to the same efforts and have proven difficult to clone.

The genetic control over asexual reproduction is an area of active research in plant biology. Some plants, such as eastern gamagrass, have the unusual ability to reproduce asexually through their seeds. Seeds are normally produced by sexual reproduction and differ from their parent. Gamagrass seeds are produced by mitotic division and are genetically identical to the parent plant. Recently, scientists were able to transfer the genes that control this ability from gamagrass to corn plants. The result is a variety of corn plant that produces seeds that germinate and grow into identical clones of the parent plant.

#### CAREER LINK

##### Horticulturist

Horticulturists research and work in plant cultivation in order to improve the quality, nutritional value, aesthetic value, and resistance to outside influences of plants. To learn more about being a horticulturist,



GO TO NELSON SCIENCE

## Animal Cloning

On July 5, 1996, the world's most famous sheep, Dolly, was born. Dolly was the first mammal cloned from an adult body cell. The challenge to overcome was that animal body cells could not be stimulated into restarting the process of growth and differentiation that begins with a fertilized egg cell.

Dr. Ian Wilmut of the Roslin Institute in Scotland used a clever technique to get around this obstacle. He knew that he might not need to rely entirely on the adult cell to produce a genetic clone. The adult cell contained all the genetic information he wanted in its nucleus, but it did not have the special characteristics of an egg cell that lead to growth and differentiation.

His technique involved two cells and three adult sheep. He obtained a body cell from the adult sheep he wished to clone and an unfertilized egg cell from a second donor sheep. Then, using microscopic surgery techniques, he was able to enucleate, or remove, the nucleus from the egg cell (**Figure 6**). Wilmut then used an electrical shock to fuse the adult body cell with the enucleated egg cell. The result was an egg cell containing the nucleus (and complete set of chromosomes) from the adult body cell of a different sheep. Once this was done, Wilmut triggered the egg cell to begin dividing and growing into an embryo. The embryo was then implanted into the uterus of a third sheep, and, five months later, Dolly was born (**Figure 7**).

The research program that resulted in the birth of Dolly was an extremely difficult and challenging one. Dolly was the only successful clone out of 277 attempts. In the last decade, success rates have increased and many more species of mammals have been cloned from adults, including goats, cows, mice, pigs, dogs, cats, rabbits, horses, and camels. There are still many problems that develop in cloned organisms. Cloned individuals typically do not live as long as normal individuals and often suffer from a variety of health complications. Dolly died prematurely of a lung disease more common in older sheep. While it is not certain that her early death was related to her being cloned, she did exhibit additional signs of premature aging, including arthritis.

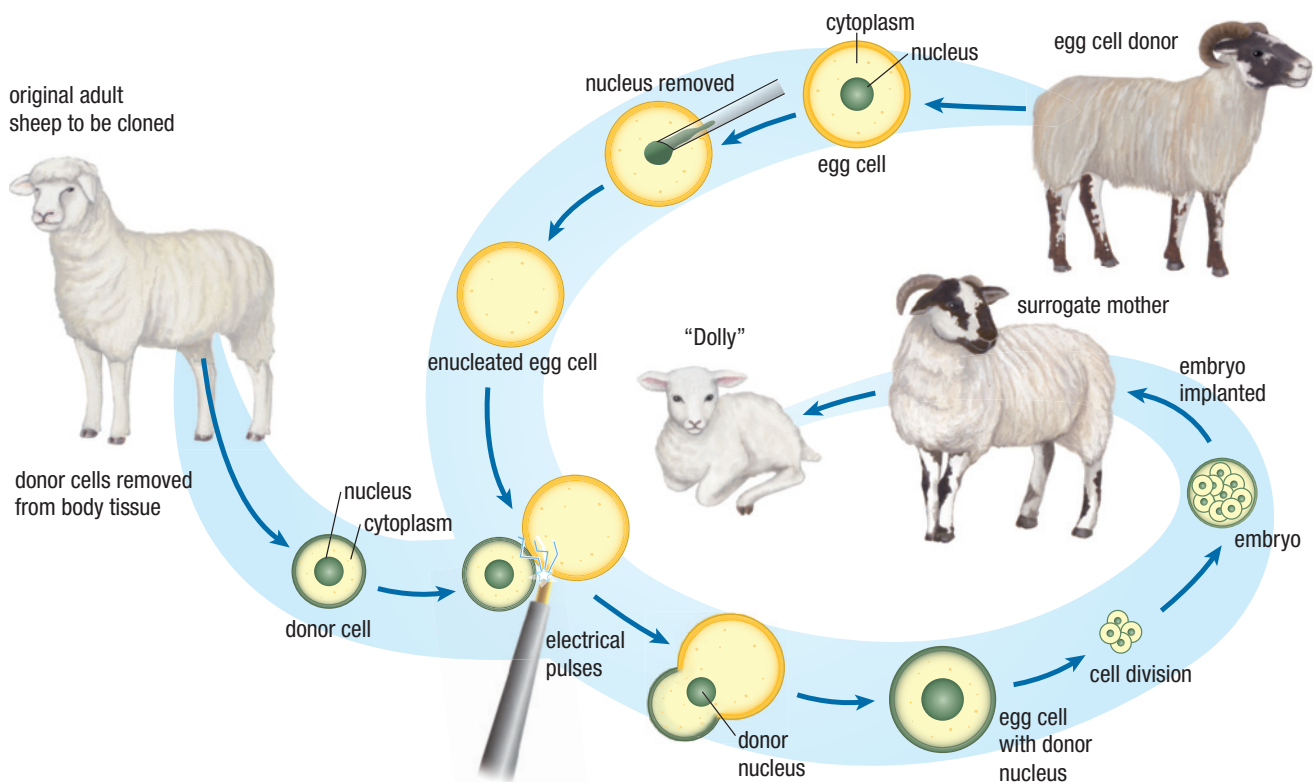
### LEARNING TIP

#### Differentiation Dead End

An unfertilized egg cell grows and differentiates into a specialized cell with a specific function. Once the cell has differentiated, it loses its ability to change into a different kind of cell.



**Figure 6** Microsurgical techniques can be used to remove the nucleus from a cell.



**Figure 7** In 1996, Dolly was the first mammal to be cloned from an adult body cell. The process involved transferring an adult cell's nucleus into an egg cell in place of the original nucleus.



**Figure 8** Prize Holstein cows can produce in excess of 75 L of milk per day. The average for the breed is closer to 30 L per day.

**genetically modified organism** an organism in which the genetic material has been altered using genetic engineering techniques

#### CAREER LINK

##### Patent Attorney

There are many ways to combine a legal career with the biological sciences. For example, biotechnology patent attorneys work to protect and control biotechnology discoveries and inventions. To learn more about the legal profession as it relates to biology,



GO TO NELSON SCIENCE

## Applications and Implications of Cloning

You might be wondering what all the fuss is about. Why spend millions of dollars developing cloning technologies? The potential benefits of cloning are numerous and the implications are dramatic.

### MASS PRODUCTION OF LIVESTOCK AND CROP PLANTS

The potential benefits of cloning are most evident in agriculture and horticulture, where prize animals and plants can be cloned on a massive scale to improve the production and quality of livestock and crop plants. By choosing parent organisms that are of the highest quality, farmers and growers can produce clones that will potentially increase yields. Thus, a dairy farmer with a herd of top-producing milking cows might have a significant advantage over a farmer with a herd of less productive cows (**Figure 8**). In this way, the production of genetically identical clones has the potential to yield significant benefits.

Innovations rarely come without costs and risks. Cloned plants and livestock may be very expensive for farmers to produce and maintain. Also, some consumers may avoid purchasing food from cloned organisms, feeling that it is unnatural or unethical. An additional concern is that although clones will all have the same inherited characteristics, some will be detrimental—for example, the same vulnerability to diseases. In this way, genetic uniformity is responsible for the greatest risks and limitations associated with the widespread use of cloned organisms.

All of these potential benefits, costs, and risks extend to society as a whole. While the quality and quantity of food may increase, available variety and choice may be reduced. Also, the long-term risks associated with reduced genetic diversity are unknown and may be substantial.

### CLONING GENETICALLY MODIFIED ORGANISMS

New biotechnology tools have given scientists the ability to alter the genetic material in an organism, producing **genetically modified organisms** (GMOs). Genetically modified organisms often carry genes that originated in a different species. These GMOs exhibit some of the characteristics of the gene donor species and are unique organisms.

We already use many genetically modified organisms daily. For example, virtually all commercial insulin is produced by bacteria and yeast that have been genetically engineered to contain copies of the human gene that codes for insulin. The bacteria and yeast use the genetic instructions to make human insulin, which is then purified and made available to people suffering from diabetes (**Figure 9(a)**).

Scientists at the University of Calgary recently inserted the human insulin gene into a safflower plant (**Figure 9(b)**). This is the first time a plant has been genetically engineered to produce insulin, and it is very cost effective. It is estimated that a hectare of cloned plants could produce 2.5 kg of insulin—enough to treat 2500 insulin patients for an entire year! The entire world's supply of insulin could be produced on 65 square kilometres of prairie farmland. 🌱



**Figure 9** (a) Humulin is identical to human insulin and is produced by genetically engineered micro-organisms. (b) Now researchers have genetically engineered safflowers to produce the same substance. They hope this will reduce the cost of this very valuable drug.



The technological challenges and costs of creating genetically modified plants and animals are extremely high, so it makes economic sense to attempt to clone these individuals once they have been created. A few potential and highly innovative applications of genetically modified organisms are listed in **Table 1**.

**Table 1** The Use of Genetically Modified (GM) Organisms in Medicine and Industry

Organism	New gene action	Benefit
GM goats	gene from the golden orb spider can be used to produce silk protein	Goats produce spider silk protein in their milk, which is then purified and used to make high-strength “spider web” fibre.
GM bananas	genes for the production of a hepatitis vaccine	Bananas would contain a vaccine—making vaccines readily available in developing countries.
GM pigs	gene involved in the production of omega-3 fatty acids	Pigs produce bacon and other pork products containing “healthy” fats.
GM potatoes	genes involved in starch production have been altered	Potatoes produce starch that is more suitable for industrial applications such as the production of biodegradable “eco-plastics.”

Despite the great medical and commercial potential for genetic engineering, many people have moral, ethical, and health concerns with the idea. They worry about the future possibility and impact on society of genetically modifying humans. You will have an opportunity to investigate and consider this important issue later on in the unit.

### CLONING ENDANGERED SPECIES

Scientists are very concerned about the number of species that are endangered. Ontario alone has 86 species of plants and animals that are currently listed as endangered and 100 more that are at risk.

Captive breeding programs can be used to help save endangered species. Unfortunately, many species from Ontario and around the world are extremely difficult to breed in captivity. Cloning provides an alternative.

In 2003, a banteng (wild bovine) from Java was successfully cloned (**Figure 10**). The success of cloning this endangered species gave scientists hope that cloning might even be used to clone extinct species.



**Figure 10** It was not until 2003 that scientists at Advanced Cell Technology announced they had successfully cloned a “normal” banteng—an endangered species.



The primary obstacle to cloning extinct species is the need for DNA, which is usually not available. In early 2009, an extinct Spanish ibex (wild goat) was cloned using a tissue sample from an adult ibex that had been frozen. The genetic material from the donor was then transferred into the egg cell of a closely related species of goat. Although the ibex later died of lung defects, the experiment opened the door to cloning extinct species.

Unfortunately, even the successful cloning of an endangered species would not guarantee its long-term survival. Just as with other clones, the lack of genetic variability is problematic. Without genetic variability among individuals, populations and entire species are vulnerable to environmental changes and disease. If we do succeed in cloning endangered and extinct species, it may be necessary to clone as many genetically different individuals as we possibly can.

Even if cloning an extinct species were successful, it is important to note that cloning would remain a last resort. In addition, cloning endangered and extinct species is a controversial issue.

## Research This

### Pet Clones

**Skills:** Researching, Analyzing, Evaluating, Communicating, Defending a Decision

SKILLS  
HANDBOOK  A2.1, A5.1








Many people are extremely fond of their pets—so much so that they are willing to spend almost any amount of money to “get them back” after they have died. Does cloning provide such an opportunity? Is it possible to clone your pet, and if so, at what cost? Will the clone really be the same as the pet it replaces?

In this activity, you will use the Internet to examine the history of pet cloning.

1. Research the short history of pet cloning, including famous pet clones such as *Carbon Copy the Cat*, *Missyplicity*, and *Lancelot Encore* (Figure 11).



**Figure 11** In 2008, an American couple paid more than \$150 000 to have their late pet dog Lancelot cloned. The puppy clone, named Lancelot Encore, was created by the South Korean biotechnology company, BioArts International.

2. Research the different kinds of pets that have been cloned.
  3. Research the cost of having a pet cloned.
  4. Share your findings with a partner. Discuss your feelings on this topic.
- A. What methods were used to clone the pets listed in Step 1?  K/U A
  - B. According to your research, what other types of pets have been cloned?  T/I A
  - C. Are cloned pets as healthy as normal animals? List three examples from your research to support your answer.  T/I
  - D. Would you agree with the concept of pet cloning if it were inexpensive—no more than the cost of purchasing a new dog or cat? Why or why not?  T/I A
  - E. What was the public reaction to the news that pet cloning had taken place?  T/I
  - F. Do you believe pet cloning is acceptable? Why or why not?  T/I A
  - G. Should individuals have the right to choose whether or not to clone their pet, or should pet cloning be regulated by governments? Explain your reasoning.  T/I A



GO TO NELSON SCIENCE

## 4.2 Summary

- Asexual reproduction results in offspring that are genetically identical to a single parent.
- Cell division produces two daughter cells that are genetically identical to each other and to the original parent cell.
- Clones have little or no genetic variability.
- Mammals have been cloned from adult cells, but only with limited success.
- Applications of biotechnology include the production of valuable pharmaceutical and commercial products, high-quality plants and livestock, and prize individual animals.
- Cloned plants and animals are more vulnerable to changes in the environment and new diseases than are populations that exhibit genetic variability.
- Cloning may prove valuable in the fight to protect endangered species.

## 4.2 Questions

1. How does asexual reproduction benefit organisms that invade new environments? **K/U A**
2. Describe the reproductive behaviour of aphids. Why might it be advantageous to only produce females asexually during the summer months but then to switch to producing both males and females and performing sexual reproduction in the fall? **K/U T/I A**
3. Describe the key events involving chromosomes that take place during the following portions of the cell cycle: **K/U**
  - (a) interphase
  - (b) prophase
  - (c) metaphase
  - (d) anaphase
  - (e) telophase
4. Compare the genetic material of cells before and after cell division. **K/U C**
5. Distinguish between a chromosome and a sister chromatid. **K/U**
6. Why might it be advantageous to clone a prize animal rather than simply breeding it with other individuals? What might be the disadvantages? **K/U A**
7. Make a set of simple labelled sketches to outline the key steps involved in cloning Dolly the sheep. **K/U C**
8. How does the use of cloned prize plants and animals reduce the possibility of improving these same species? **K/U A**
9. How has the use of genetic engineering and cloning benefited people suffering from diabetes? **K/U A**
10. The couple that paid more than \$150 000 to have their deceased pet dog Lancelot cloned already had eight other dogs. How does this news story make you feel? Do you think it is acceptable to spend that much money on cloning a pet? How does it compare to spending a similar amount of money on an exotic sports car? **C A**
11. There are many applications of cloning technology. List the applications that you think are most acceptable and those that are least acceptable. Explain your reasoning. **T/I A**
12. There is little doubt that it will soon be technologically possible to clone humans. Comment on the concept of cloning humans. What arguments do you think people will make in support of, and in opposition to, human cloning? **C A**
13. Canadian scientists have successfully inserted the human insulin gene into safflowers, which can now produce insulin at low cost. Go online to research the current status of this technology, and then answer questions (a) through (d). **T/I C**
  - (a) Are safflowers being used for the commercial production of human insulin?
  - (b) Who “owns” the rights to this genetically modified organism? Is this a private company or a public institution?
  - (c) Are safflowers being considered for any other gene transfers? If so, describe them.
  - (d) Who has funded this scientific research and technology?



GO TO NELSON SCIENCE