Chapter 8

Cellular Reproduction: Cells from Cells

Biology and Society: Virgin Birth of a Dragon

- In 2002, zookeepers at the Chester Zoo were surprised to discover that their Komodo Dragon laid eggs.
  - The female dragon had not been in the company of a male.
  - The eggs developed without fertilization, in a process called parthenogenesis.
  - DNA analysis confirmed that her offspring had genes only from her.

Biology and Society: Virgin Birth of a Dragon

- A second European Komodo dragon is now known to have reproduced
  - asexually, via parthenogenesis, and
  - sexually.

Figure 8.0

WHAT CELL REPRODUCTION ACCOMPLISHES

- Reproduction
  - may result in the birth of new organisms but
  - more commonly involves the production of new cells.
- When a cell undergoes reproduction, or **cell division**, two "daughter" cells are produced that are genetically identical
  - to each other and
  - to the "parent" cell.
- Before a parent cell splits into two, it duplicates its **chromosomes**, the structures that contain most of the cell's DNA.
- During cell division, each daughter cell receives one identical set of chromosomes from the lone, original parent cell.

- Cell division plays important roles in the lives of organisms.
- Cell division
  - replaces damaged or lost cells,
  - permits growth, and
  - allows for reproduction.

Figure 8.1a
Figure 8.1aa
Figure 8.1ab

- In **asexual reproduction**,
  - single-celled organisms reproduce by simple cell division and
  - there is no fertilization of an egg by a sperm.
- Some multicellular organisms, such as sea stars, can grow new individuals from fragmented pieces.
- Growing a new plant from a clipping is another example of asexual reproduction.

Figure 8.1b
Figure 8.1ba
Figure 8.1bb
Figure 8.1bc

- In asexual reproduction, the lone parent and its offspring have identical genes.
- Mitosis is the type of cell division responsible for
  - asexual reproduction and
  - growth and maintenance of multicellular organisms.

- **Sexual reproduction** requires fertilization of an egg by a sperm using a special type of cell division called meiosis.
- Thus, sexually reproducing organisms use
  - meiosis for reproduction and
  - mitosis for growth and maintenance.

- In a eukaryotic cell,
  - most genes are located on chromosomes in the cell nucleus and
  - a few genes are found in DNA in mitochondria and chloroplasts.

Eukaryotic Chromosomes

- Each eukaryotic chromosome contains one very long DNA molecule, typically bearing thousands of genes.
- The number of chromosomes in a eukaryotic cell depends on the species.

Figure 8.2

- Chromosomes are
  - made of **chromatin**, fibers composed of roughly equal amounts of DNA and protein molecules and
  - not visible in a cell until cell division occurs.

Figure 8.3

- The DNA in a cell is packed into an elaborate, multilevel system of coiling and folding.
- **Histones** are proteins used to package DNA in eukaryotes.
- **Nucleosomes** consist of DNA wound around histone molecules.

Figure 8.4
Figure 8.4a
Figure 8.4b

- Before a cell divides, it duplicates all of its chromosomes, resulting in two copies called **sister chromatids** containing identical genes.
- Two sister chromatids are joined together tightly at a narrow "waist" called the **centromere**.
- When the cell divides, the sister chromatids of a duplicated chromosome separate from each other.
- Once separated, each chromatid is
  - considered a full-fledged chromosome and
  - identical to the original chromosome.

Figure 8.5

The Cell Cycle

- A **cell cycle** is the ordered sequence of events that extend
  - from the time a cell is first formed from a dividing parent cell
  - to its own division into two cells.
- The cell cycle consists of two distinct phases:
  - interphase and
  - the mitotic phase.

Figure 8.6
Figure 8.6a
Figure 8.6b

- Most of a cell cycle is spent in **interphase**.
- During interphase, a cell
  - performs its normal functions,
  - doubles everything in its cytoplasm, and
  - grows in size.
- The **mitotic (M) phase** includes two overlapping processes:
  - **mitosis**, in which the nucleus and its contents divide evenly into two daughter nuclei and
  - **cytokinesis**, in which the cytoplasm is divided in two.

Mitosis and Cytokinesis

- During mitosis the **mitotic spindle**, a football-shaped structure of microtubules, guides the separation of two sets of daughter chromosomes.
- Spindle microtubules grow from structures within the cytoplasm called **centrosomes**.
- Mitosis consists of four distinct phases:
  - **Prophase**

Figure 8.7a
Figure 8.7aa
Figure 8.7ab
Figure 8.7ac
Figure 8.7ad

- Prophase
- **Metaphase**

Figure 8.7b
Figure 8.7bb

- Prophase
- Metaphase
- **Anaphase**

Figure 8.7b
Figure 8.7bc

- Prophase
- Metaphase
- Anaphase

- **Telophase**

Figure 8.7ba
Figure 8.7bd

- Cytokinesis usually
  - begins during telophase,
  - divides the cytoplasm, and
  - is different in plant and animal cells.
- In animal cells, cytokinesis
  - is known as cleavage and
  - begins with the appearance of a cleavage furrow, an indentation at the equator of the cell.

Figure 8.8a
Figure 8.8aa
Figure 8.8ab

- In plant cells, cytokinesis begins when vesicles containing cell wall material collect at the middle of the cell and then fuse, forming a membranous disk called the **cell plate**.

Figure 8.8b
Figure 8.8ba
Figure 8.8bb

Cancer Cells: Growing Out of Control

- Normal plant and animal cells have a **cell cycle control system** that consists of specialized proteins, which send "stop" and "go-ahead" signals at certain key points during the cell cycle.

What Is Cancer?

- Cancer is a disease of the cell cycle.
- Cancer cells do not respond normally to the cell cycle control system.
- Cancer cells can form **tumors**, abnormally growing masses of body cells.
- If the abnormal cells remain at the original site, the lump is called a **benign tumor**.
- The spread of cancer cells beyond their original site of origin is **metastasis**.
- **Malignant tumors** can
  - spread to other parts of the body and
  - interrupt normal body functions.
- A person with a malignant tumor is said to have **cancer**.

Figure 8.9

Cancer Treatment

- Cancer treatment can involve
  - **radiation therapy**, which damages DNA and disrupts cell division, and
  - **chemotherapy**, the use of drugs to disrupt cell division.

Cancer Prevention and Survival

- Certain behaviors can *decrease* the risk of cancer:
  - not smoking,
  - exercising adequately,
  - avoiding exposure to the sun,
  - eating a high-fiber, low-fat diet,
  - performing self-exams, and
  - regularly visiting a doctor to identify tumors early.
- Sexual reproduction
  - depends on meiosis and fertilization and
  - produces offspring that contain a unique combination of genes from the parents.

Figure 8.10

Homologous Chromosomes

- Different individuals of a single species have the same
  - number and
  - types of chromosomes.
- A human **somatic cell**
  - is a typical body cell and
  - has 46 chromosomes.
- A **karyotype** is an image that reveals an orderly arrangement of chromosomes.
- **Homologous chromosomes**

- are matching pairs of chromosomes that
- can possess different versions of the same genes.

Figure 8.11
Figure 8.11a

- Humans have
  - two different **sex chromosomes**, X and Y, and
  - 22 pairs of matching chromosomes, called **autosomes**.

Gametes and the Life Cycle of a Sexual Organism

- The **life cycle** of a multicellular organism is the sequence of stages leading from the adults of one generation to the adults of the next.

Figure 8.12

- Humans are **diploid** organisms with
  - body cells containing two sets of chromosomes and
  - **haploid** gametes that have only one member of each homologous pair of chromosomes.
- In humans, a haploid sperm fuses with a haploid egg during **fertilization** to form a diploid **zygote**.
- Sexual life cycles involve an alternation of diploid and haploid stages.
- Meiosis produces haploid gametes, which keeps the chromosome number from doubling every generation.

Figure 8.13-1
Figure 8.13-2
Figure 8.13-3

The Process of Meiosis

- In **meiosis**,
  - haploid daughter cells are produced in diploid organisms,
  - interphase is followed by two consecutive divisions, meiosis I and meiosis II, and
  - crossing over occurs.

Figure 8.14a
Figure 8.14aa
Figure 8.14ab
Figure 8.14ac
Figure 8.14ad
Figure 8.14b
Figure 8.14ba
Figure 8.14bb
Figure 8.14bc
Figure 8.14bd

Review: Comparing Mitosis and Meiosis

- In mitosis and meiosis, the chromosomes duplicate only once, during the preceding interphase.
- The number of cell divisions varies:
  - Mitosis uses one division and produces two diploid cells.
  - Meiosis uses two divisions and produces four haploid cells.
- All the events unique to meiosis occur during meiosis I.

Figure 8.15
Figure 8.15a
Figure 8.15b

The Origins of Genetic Variation

- Offspring of sexual reproduction are genetically different from their parents and one another.

Independent Assortment of Chromosomes

- When aligned during metaphase I of meiosis, the side-by-side orientation of each homologous pair of chromosomes is a matter of chance.
- Every chromosome pair orients independently of all of the others at metaphase I.
- For any species, the total number of chromosome combinations that can appear in the gametes due to independent assortment is
  - 2^n, where n is the haploid number.
- For a human,
  - $n = 23$.
  - With $n = 23$, there are 8,388,608 different chromosome combinations possible in a gamete.

Figure 8.16-1
Figure 8.16-2
Figure 8.16-3

Random Fertilization

- A human egg cell is fertilized randomly by one sperm, leading to genetic variety in the zygote.
- If each gamete represents one of 8,388,608 different chromosome combinations, at fertilization, humans would have 8,388,608 × 8,388,608, or more than 70 trillion different possible chromosome combinations.
- So we see that the random nature of fertilization adds a huge amount of potential variability to the offspring of sexual reproduction.

Figure 8.17

Crossing Over

- In **crossing over**,
  - nonsister chromatids of homologous chromosomes exchange corresponding segments and
  - **genetic recombination**, the production of gene combinations different from those carried by parental chromosomes, occurs.

Figure 8.18
Figure 8.18a
Figure 8.18b

The Process of Science: Do All Animals Have Sex?

- **Observation**: No scientists have ever found male bdelloid rotifers, a microscopic freshwater invertebrate.
- **Question:** Does this entire class of animals reproduce solely by asexual means?

The Process of Science: Do All Animals Have Sex?

- **Hypothesis**: Bdelloid rotifers have thrived for millions of years despite a lack of sexual reproduction.
- **Prediction**: Bdelloid rotifers would display much more variation in their pairs of homologous genes than most organisms.
- **Experiment**: Researchers compared sequences of a particular gene in bdelloid and non-bdelloid rotifers.
- **Results**:
  - Non-bdelloid sexually reproducing rotifers had a nearly identical homologous gene, differing by only 0.5% on average.
  - The two versions of the same gene in asexually reproducing bdelloid rotifers differed by 3.5–54%.
- **Conclusion**: Bdelloid rotifers have evolved for millions of years without any sexual reproduction.

Figure 8.19

- What happens when errors occur in meiosis?
- Such mistakes can result in genetic abnormalities that range from mild to fatal.

How Accidents during Meiosis Can Alter Chromosome Number

- In **nondisjunction**,
  - the members of a chromosome pair fail to separate at anaphase,
  - producing gametes with an incorrect number of chromosomes.
- Nondisjunction can occur during meiosis I or II.

Figure 8.20-1
Figure 8.20-2
Figure 8.20-3

- If nondisjunction occurs, and a normal sperm fertilizes an egg with an extra chromosome, the result is a zygote with a total of $2n + 1$ chromosomes.
- If the organism survives, it will have
  - an abnormal karyotype and
  - probably a syndrome of disorders caused by the abnormal number of genes.

Figure 8.21

Down Syndrome: An Extra Chromosome 21

- **Down syndrome**
  - is also called **trisomy 21**,
  - is a condition in which an individual has an extra chromosome 21, and
  - affects about one out of every 700 children.

Figure 8.22
Figure 8.22a
Figure 8.22b

- The incidence of Down syndrome in the offspring of normal parents increases markedly with the age of the mother.

Figure 8.23

Abnormal Numbers of Sex Chromosomes

- Nondisjunction in meiosis
  - can lead to abnormal numbers of sex chromosomes but
  - seems to upset the genetic balance less than unusual numbers of autosomes, perhaps because the Y chromosome is very small and carries relatively few genes.

Table 8.1

Evolution Connection: The Advantages of Sex

- Asexual reproduction conveys an evolutionary advantage when plants are
  - sparsely distributed and unlikely to be able to exchange pollen or
  - superbly suited to a stable environment.

- Asexual reproduction also eliminates the need to expend energy
  - forming gametes and
  - copulating with a partner.

Figure 8.24

- Sexual reproduction may convey an evolutionary advantage by
  - speeding adaptation to a changing environment or
  - allowing a population to more easily rid itself of harmful genes.

Figure 8.UN01
Figure 8.UN02
Figure 8.UN03
Figure 8.UN04
Figure 8.UN05
Figure 8.UN06