Development and Meiosis (Learning Objectives)

- Review the basic processes of development and identify the diploid and haploid cells involved.
- Learn the basic structure of the reproductive systems of males and females.
- Explain the structure and function of components of the male and females reproductive systems.
- Explain the importance of sexual reproduction for generating genetic diversity among populations.
- Explain the two divisions of meiosis and the products of each in terms of number of cells and genetic identity of daughter cells and mother germline cells.
- Learn the phases of meiosis I and meiosis II and the events that occur in each.
- Recognize the importance of the crossing over events of prophase I in creating recombinant chromosomes from genes coming from both parents.
- Review the sources of variability in sexually reproducing organisms.
- Compare and contrast Mitosis with Meiosis.
- Explain the importance of the events of anaphase and the role of non-disjunction in producing gametes that can give rise to chromosomal anomalies.
Development and Meiosis (Learning Objectives) (cont’d)

- Explain nondisjunction and its role in causing chromosomal abnormalities.
- Review the sources of genetic variability in sexually reproducing organisms
- Compare and contrast Spermatogenesis with Oogenesis:
  - Relate each of the cells involved to the mother cell and daughter cells of Meiosis I and Meiosis II.
  - Timing of each process
  - Structures of the mature sperm and ovum
- Review the early events of early embryonic development from fertilization to implantation: the events and where they take place.
  - Explain the three embryonic germ layers and their relationship to different organs and organ systems.
- Recognize the embryonic supportive structures and their importance.
- Explain the causes of multiple births: dizygotic (Fraternal) twins and monozygotic (identical) twins.
- Explain the critical periods of embryonic development and the role of faulty genes and the environment on the developing embryo or fetus.
Stages of the Human Life Cycle

**Development** - the process of forming an adult from a single-celled embryo, a diploid *zygote*

**Gametes** are haploid sex cells
- **Sperm** - male
- **Oocyte** - female
Reproductive system components

- **Gonads-**
  One pair where gametes are formed

- **Tubular structures**
  for gametes to pass through

- **Secretions**
The Male Reproductive System

Figure 3.1

- Urinary bladder
- Pubic bone
- Penis
- Ductus deferens (2)
- Seminal vesicle (1 of 2)
- Rectum
- Prostate gland
- Bulbourethral gland (1 of 2)
- Urethra
- Scrotum
- Testis (1 of 2)
- Anus
- Epididymis (1 of 2)
The Male Reproductive System

Gonads- **testes**

Male gamete- **sperm**

Tubular structures-
  - **seminiferous tubules**- germ cells divide to form sperms
  - **Epididymis** maturation and storage of sperms
  - **Ductus deferens**- connects to urethra

Glands
  - Seminal vesicles
  - Prostate gland
  - Bulbourethral gland

Penis
The Female Reproductive System

Figure 3.2
The Female Reproductive System

Gonads- **ovaries**
Female gamete- **Oocyte**
Tubular structure- Falopian or uterine tubes
Muscular structure- uterus and its lining and lower part, cervix
Vagina
The Female Reproductive System

- Released oocyte picked by the fingerlike projections of the uterine tubes.
- A sperm-fertilized oocyte continues to the uterus where it divides and develops
- Otherwise it is expelled, with the uterine-lining via the menstrual flow

Hormonal control the cycle of oocyte development
MEIOSIS and Genetic Variability

The somatic (body) cells of each species contain a specific number of chromosomes.

Human cells have 46 chromosomes: 23 pairs of homologous chromosomes.

Homologous pairs carry genes for the same characteristics at the same place, or locus.

Chromosomes

Centromere

Sister chromatids
Meiosis

The cell division that produces *gametes* with half the number of chromosomes

Occurs in special diploid cells called germ or germline cells

Ensures genetic variability
Like Mitosis, Meiosis is preceded by duplication of chromosomes during the S phase of the cell cycle.

Meiosis consists of two divisions

- **Meiosis I =**
- **Meiosis II =**

Each division contains a prophase, a metaphase, an anaphase and a telophase.

- Produces four genetically non-identical cells with half the number of chromosomes in the mother germ cell.
Meiosis animation

http://www.sumanasinc.com/webcontent/anisamples/majorsbiology/meiosis.html

www.cellsalive.com / Meiosis

Stages of Meiosis

http://highered.mcgraw-hill.com/sites/0072437316/student_view0/chapter12/animations.html#
Crossing-over

- During prophase I
- Creates recombinant chromosomes
- Genes from both parents are shuffled between the homologous chromosomes

Figure 3.5
Figure 3.4

**Meiosis I**

**Prophase I (early)**
Synapsis and crossing over occurs.

**Prophase I (late)**
Chromosomes condense, become visible. Spindle forms. Nuclear envelope fragments. Spindle fibers attach to each chromosome.

**Metaphase I**
Paired homologous chromosomes align along equator of cell.

**Anaphase I**
Homologous chromosomes separate to opposite poles of cell.

**Telophase I**
Nuclear envelopes partially assemble around chromosomes. Spindle disappears. Cytokinesis divides cell into two.
Prophase I

- Homologs pair-up and undergo crossing over
- Chromosomes condense
- Spindle forms
- Nuclear envelope breaks down

Prophase I (early)
Synapsis and crossing over occurs.

Prophase I (late)
Chromosomes condense, become visible. Spindle forms. Nuclear envelope fragments. Spindle fibers attach to each chromosome.
Metaphase I

Homologous pairs align along the equator of the cell

The random alignment pattern determines the combination of maternal and paternal chromosomes in the gametes
Independent Assortment

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Anaphase I

Homologs separate and move to opposite poles of the cell

Sister chromatids remain attached at their centromeres
Telophase I

Nuclear envelope reforms

Spindle disappears

Cytokinesis divides cell into two
Interkinesis

A short interphase between the two meiotic divisions

Chromosomes unfold into very thin threads

Proteins are manufactured

However, DNA is NOT replicated a second time
Figure 3.4

**Meiosis II**

- **Prophase II**: Nuclear envelope fragments. Spindle forms and fibers attach to both chromosomes.
- **Metaphase II**: Chromosomes align along equator of cell.
- **Anaphase II**: Sister chromatids separate to opposite poles of cell.
- **Telophase II**: Nuclear envelopes assemble around two daughter nuclei. Chromosomes decondense. Spindle disappears. Cytokinesis divides cells.

Four nonidentical haploid daughter cells.
Prophase II

Chromosomes are again condensed and visible
Spindle forms
Nuclear envelope fragments

Metaphase II

Chromosomes align along the equator of the cell
Anaphase II

Centromeres divide
Sister chromatids separate to opposite cell poles

Telophase II

Nuclear envelope reforms
Chromosomes uncoil
Spindle disappears
Results of Meiosis

Four haploid cells containing a single copy of the genome

Each cell is unique – carries a new assortment of genes and chromosomes
Sources of genetic variation in sexually reproducing organisms

1. Independent assortment of chromosomes during meiosis
2. Crossing over during meiosis
3. Random fertilization
**MITOSIS**

- **Prophase**
  - Duplicated chromosome (two sister chromatids)
  - Chromosome replication
  - Parent cell (before chromosome replication)

- **Metaphase**
  - Chromosomes align at the metaphase plate

- **Anaphase**
  - Sister chromatids separate during anaphase

- **Telophase**
  - Daughter cells of mitosis
  - $2n = 4$

**MEIOSIS**

- **Prophase I**
  - Chromosome replication
  - Tetrad formed by synopsis of homologous chromosomes

- **Metaphase I**
  - Tetrads align at the metaphase plate

- **Anaphase I**
  - Homologous chromosomes separate during anaphase I; sister chromatids remain together

- **Telophase I**
  - Daughter cells of meiosis I
  - Haploid $n = 2$

- **MEIOSIS II**
  - Daughter cells of meiosis II
  - No further chromosomal replication; sister chromatids separate during anaphase II

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### Comparison of Mitosis and Meiosis

<table>
<thead>
<tr>
<th>Mitosis</th>
<th>Meiosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>One division</td>
<td>Two divisions</td>
</tr>
<tr>
<td>Two daughter cells per cycle</td>
<td>Four daughter cells per cycle</td>
</tr>
<tr>
<td>Daughter cells genetically identical</td>
<td>Daughter cells genetically different</td>
</tr>
<tr>
<td>Chromosome number of daughter cells same as that of parent cell (2n)</td>
<td>Chromosome number of daughter cells half that of parent cell (1n)</td>
</tr>
<tr>
<td>Occurs in somatic cells</td>
<td>Occurs in germline cells</td>
</tr>
<tr>
<td>Occurs throughout life cycle</td>
<td>In humans, completes after sexual maturity</td>
</tr>
<tr>
<td>Used for growth, repair, and asexual reproduction</td>
<td>Used for sexual reproduction, producing new gene combinations</td>
</tr>
</tbody>
</table>
Chromosome Abnormalities involving chromosome numbers are caused by non-disjunction during anaphase
- Homologous chromosomes during Meiosis I
- Sister chromatids during Meiosis II
Spermatogenesis

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Spermatogonium (diploid) → Mitosis → Primary spermatocyte (diploid) → Meiosis I → Meiosis II → Spermatid (haploid) → Maturation → Sperm (haploid)

- Autosomes
- Sex chromosomes

2n → 4n → 2n → 1n

Figure 3.7
Spermatogenesis

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Figure 3.7

Spermatogonium

Stem Cell (diploid)

Penis

Testis

Seminiferous tubule

Tubule wall

Diploid cell

Primary spermatocyte (diploid)

Secondary spermatocyte (haploid)

Developing sperm cell (haploid)

Sperm cells (haploid)

Meiosis Meiosis

Mitosis I II

4n diploid

Figure 3.8
Spermatogenesis

A continuous process

Spermatogonium (diploid)

Divides by mitosis: producing a stem cell and a specialized primary spermatocyte

Primary spermatocyte (diploid- 2 n)

Goes through S phase (4 n)

Divides by Meiosis:

- Meiosis I produces two secondary spermatocytes (2 n)
- Meiosis II produces four haploid spermatids (1 n)

Spermatids mature into tad-pole shaped spermatozoa
Spermatogenesis

Figure 3.9
Oogenesis

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First polar body may divide (haploid)

Polar bodies die

Mature egg

Figure 3.11
Oogenesis

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Maturing oocytes

Uterine tube

Fertilization and meiosis II

Meiosis I

Secondary oocyte

Ovulation

Ovum (egg)
Oogenesis

An **Oogonium** (diploid)
Divides by mitosis produces a stem cell and a specialized **primary oocyte**

In meiosis I, the primary oocyte (diploid)
Divides by **Meiosis**
Meiosis I produces 2 unequal cells:
  - a small **polar body** and
  - a large **secondary oocyte**

In **Meiosis II**, the secondary oocyte divides another **polar body**
a mature haploid **ovum**
Oogenesis is a discontinuous process

Meiosis in females begins in the fetal stage of development, before birth
- Oocytes arrest at prophase I until puberty
- After puberty, meiosis I continues in one or several oocytes each month but halts again at metaphase II
- Meiosis is only completed if the ovum is fertilized
Fertilization

Union of sperm and ovum

In the female, sperm are capacitated and drawn to the secondary oocyte

Acrosomal enzymes aid sperm penetration

Chemical and electrical changes in the oocyte surface block entry of more sperm

The two sets of chromosomes fuse into one nucleus, forming the **zygote**
Fertilization

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Figure 3.13

a. Diagram of fertilization showing polar body, corona radiata, cytoplasm of ovum, second meiotic spindle, zona pellucida, plasma membrane of ovum, and sperm.

b. Image of fertilization, credited to Brand X Pictures RF.
Cleavage

A period of frequent mitotic divisions
  - Resulting cells are called blastomeres

Developing embryo becomes a solid ball of
  16+ cells called a morula

The ball of cells hollows out to form a
  blastocyst
Blastocyst

Consists of two main parts
- **Inner cell mass (ICM)**, which develops into the embryo
- **Trophoblast**, which develops into the placenta

**Implantation** in the uterus occurs around day 7

Certain blastocyst cells secrete human chorionic gonadotropin (hCG)
- A sign of pregnancy
From Ovulation to Implantation

Figure 3.14
Gastrulation

The primary germ layers form in the second week after fertilization

- **Ectoderm** (outermost layer)
- **Mesoderm** (middle layer)
- **Endoderm** (innermost layer)

This three-layered structure is the **gastrula**

Cells in each germ layer begin to form specific organs
Supportive Structures

Structures that support and protect the embryo include:

- Chorionic villi
- Yolk sac
- Allantois
- Umbilical cord
- Amniotic sac

By 10 weeks the placenta is fully formed
The Primordial Embryo

Figure 3.15
# Stages of Prenatal Development

## Table 3.2  Stages and Events of Early Human Prenatal Development

<table>
<thead>
<tr>
<th>Stage</th>
<th>Time Period</th>
<th>Principal Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilized ovum</td>
<td>12–24 hours following ovulation</td>
<td>Oocyte fertilized; zygote has 23 pairs of chromosomes and is genetically distinct</td>
</tr>
<tr>
<td>Cleavage</td>
<td>30 hours to third day</td>
<td>Mitosis increases cell number</td>
</tr>
<tr>
<td>Morula</td>
<td>Third to fourth day</td>
<td>Solid ball of cells</td>
</tr>
<tr>
<td>Blastocyst</td>
<td>Fifth day through second week</td>
<td>Hollowed ball forms trophoblast (outside) and inner cell mass, which implants and flattens to form embryonic disc</td>
</tr>
<tr>
<td>Gastrula</td>
<td>End of second week</td>
<td>Primary germ layers form</td>
</tr>
</tbody>
</table>
The Embryo Develops

**Organogenesis** is the transformation of the simple three germ layers into distinct organs

During week 3, a band called the primitive streak appears along the back of the embryo

This is followed rapidly by the notochord, neural tube, heart, central nervous system, limbs, digits, and other organ rudiments

By week 8, all the organs that will be present in the newborn have begun to develop

- The prenatal human is now called a **fetus**
The Embryo Develops

Figure 3.18

a. 28 days
b. 49 days

4–6 mm

13–22 mm

a: © Petit Format/Nestle/Photo Researchers;
b: © Petit Format/SPL/Photo Researchers
The Fetus Grows

During the fetal period, structures grow, specialize and begin to interact.

Bone replaces cartilage in the skeleton.

Body growth catches up with the head.

Sex organs become more distinct.

In the final trimester, the fetus moves and grows rapidly, and fat fills out the skin.

The digestive and respiratory systems mature last.
Multiple Births

Dizygotic twins (Fraternal)
- Arise from two fertilized ova
- Same genetic relationship as any two siblings

Monozygotic twins (Identical)
- Arise from a single fertilized ovum
- Embryo splits early during development
- Twins may share supportive structures
Figure 3.16

Two-cell stage

a. Identical twins with separate amnions and chorions
b. Identical twins that share an amnion and chorion
c. Identical twins that share a chorion but have separate amnions
Birth Defects

The time when a particular structure is sensitive to damage is called its **critical period**

Birth defects can result from a faulty gene or environmental insult

Most birth defects develop during the embryonic period
  - These are more severe than those that arise during the fetal period
Critical Periods of Development

- Reproductive system
- Ears
- Eyes
- Arms and legs
- Heart

Central nervous system

Sensitivity to teratogens during pregnancy
- Thalidomide
- Accutane
- Diethylstilbestrol

Figure 3.19
Teratogens

Chemical or other agents that cause birth defects

Examples
- Thalidomide
- Cocaine
- Cigarettes
- Alcohol
- Some nutrients
- Some viruses
Fetal Alcohol Syndrome

Figure 3.20