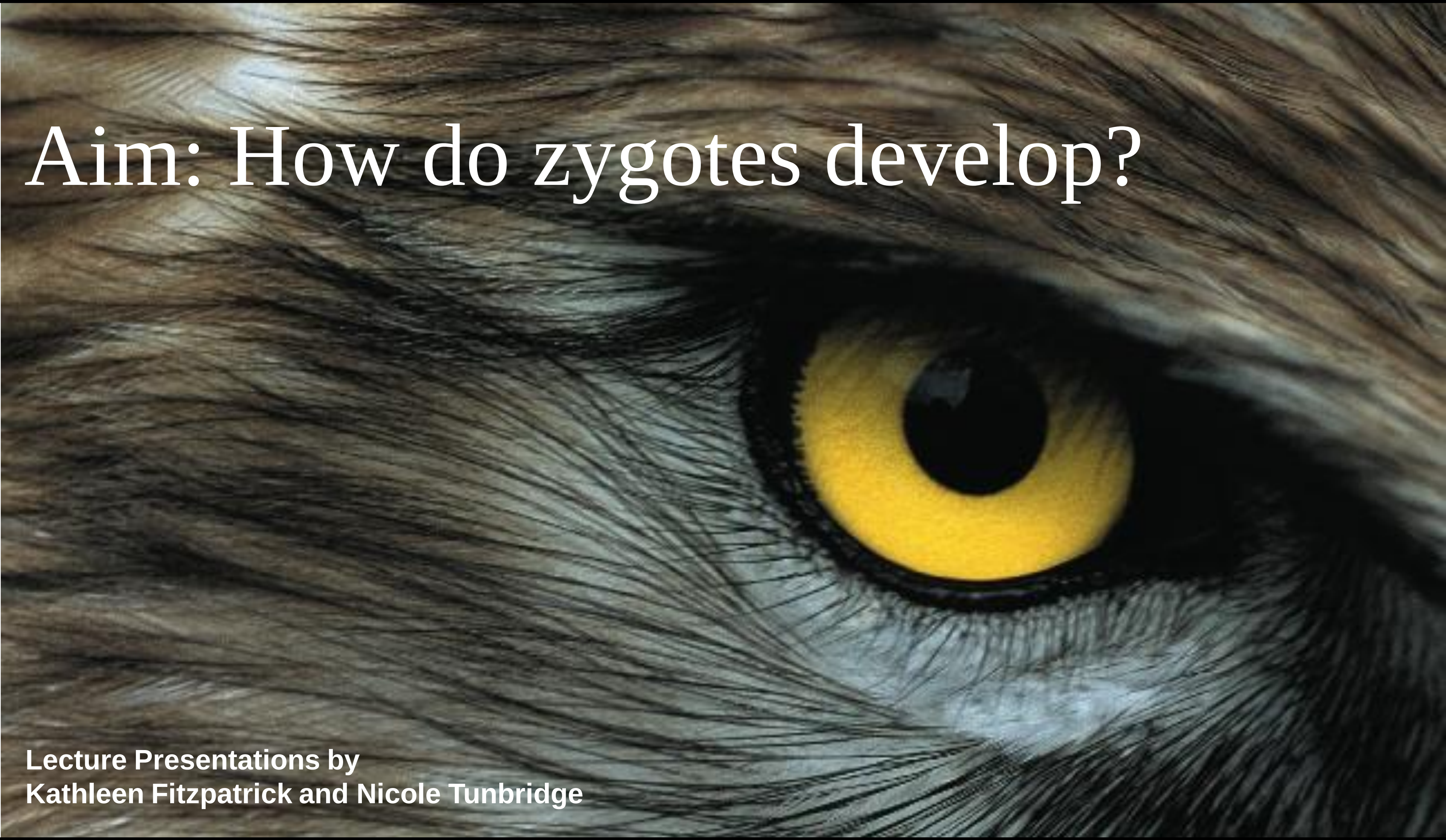
CAMPBELL **BIOLOGY IN FOCUS**

Urry • Cain • Wasserman • Minorsky • Jackson • Reece



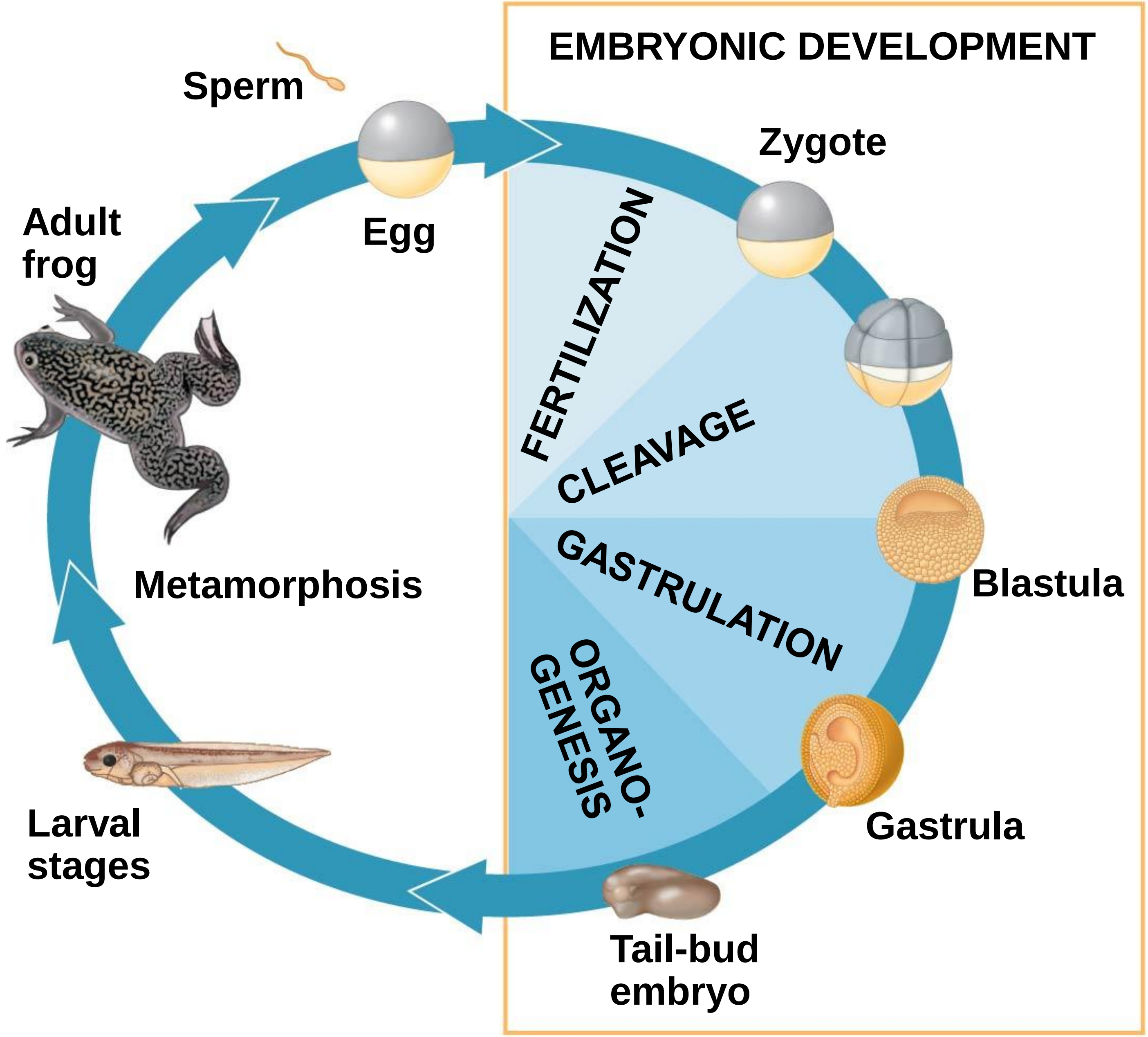
Aim: How do zygotes develop?

Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge

Fertilization, cleavage, and gastrulation initiate embryonic development

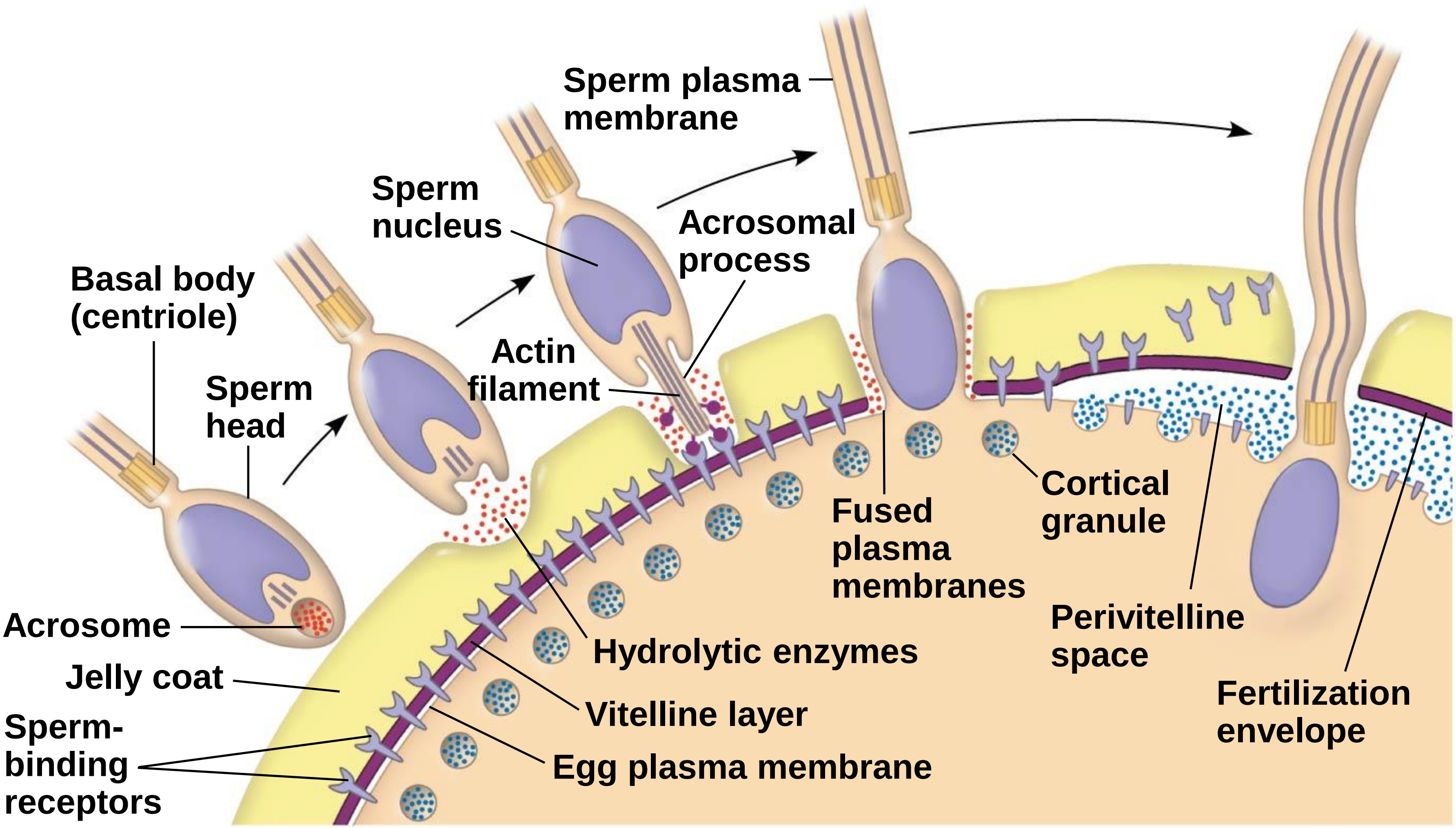
- Across animal species, embryonic development involves common stages occurring in a set order
- First is fertilization, which forms a zygote
- During the cleavage stage, a series of mitoses divide the zygote into a many-celled embryo
- The resulting blastula then undergoes rearrangements into a three-layered embryo called a gastrula

Figure 36.14



EMBRYONIC DEVELOPMENT
Sperm
Egg
Zygote
Adult frog
FERTILIZATION
CLEAVAGE
GASTRULATION
ORGANO-GENESIS
Blastula
Metamorphosis
Gastrula
Larval stages
Tail-bud embryo

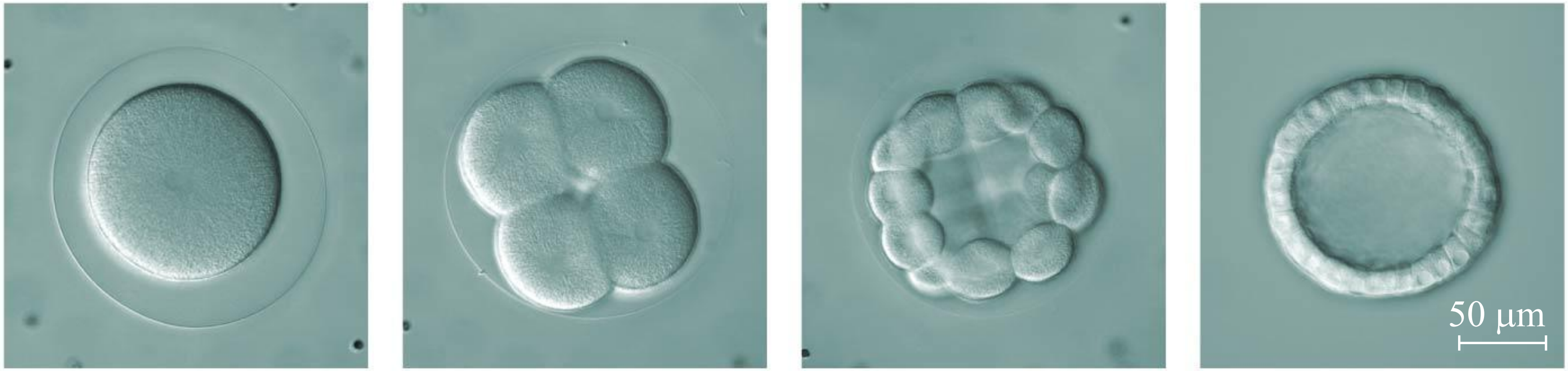
Figure 35.15-5



Cleavage and Gastrulation

- Fertilization is followed by **cleavage**, a period of rapid cell division without growth
- Cleavage partitions the cytoplasm of one large cell into many smaller cells
- The **blastula** is a ball of cells with a fluid-filled cavity called a **blastocoel**
- The blastula is produced after about five to seven cleavage divisions

Figure 36.17



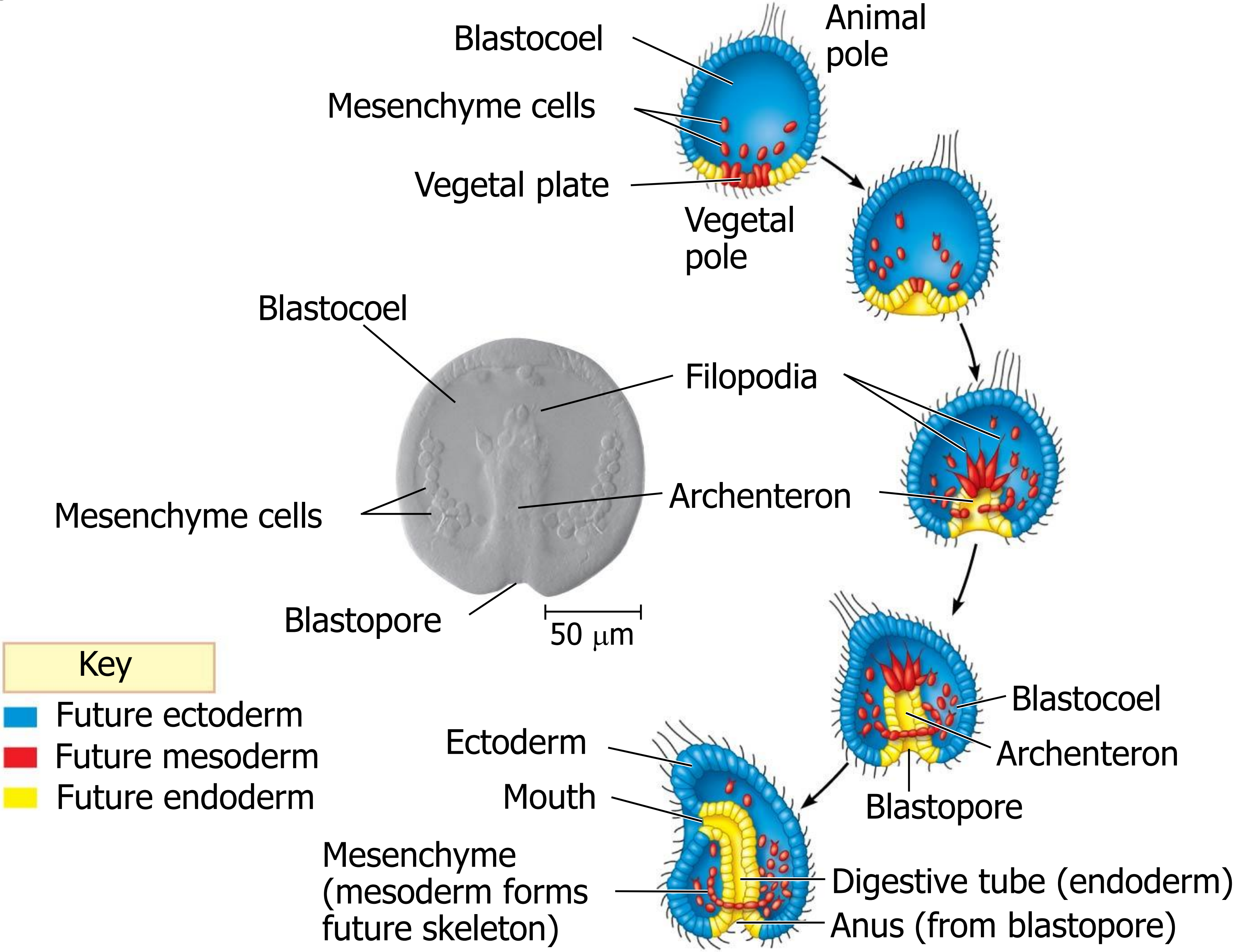
(a) Fertilized egg (b) Four-cell stage (c) Early blastula (d) Later blastula

- After cleavage, the rate of cell division slows
- The remaining stages of embryonic development are responsible for **morphogenesis**, the cellular and tissue-based processes by which the animal body takes shape

- During **gastrulation**, a set of cells at or near the surface of the blastula moves to an interior location, cell layers are established, and a primitive digestive tube forms
- The hollow blastula is reorganized into a two- or three-layered embryo called a **gastrula**

- The cell layers produced by gastrulation are called germ layers
- The **ectoderm** forms the outer layer and the **endoderm** the inner layer
- In vertebrates and other animals with bilateral symmetry, a third germ layer, the **mesoderm**, forms between the endoderm and ectoderm

Figure 36.18



Blastocoel
Animal pole
Mesenchyme cells
Vegetal plate
Vegetal pole
Blastocoel
Filopodia
Archenteron
Mesenchyme cells
Blastopore
50 μm
Key
Future ectoderm
Future mesoderm
Future endoderm
Blastocoel
Archenteron
Blastopore
Ectoderm
Mouth
Mesenchyme (mesoderm forms future skeleton)
Digestive tube (endoderm)
Anus (from blastopore)

Figure 36.19

ECTODERM (outer layer of embryo)

- Epidermis of skin and its derivatives (including sweat glands, hair follicles)
- Nervous and sensory systems
- Pituitary gland, adrenal medulla
- Jaws and teeth
- Germ cells

MESODERM (middle layer of embryo)

- Skeletal and muscular systems
- Circulatory and lymphatic systems
- Excretory and reproductive systems (except germ cells)
- Dermis of skin
- Adrenal cortex

ENDODERM (inner layer of embryo)

- Epithelial lining of digestive tract and associated organs (liver, pancreas)
- Epithelial lining of respiratory, excretory, and reproductive tracts and ducts
- Thymus, thyroid, and parathyroid glands

A program of differential gene expression leads to the different cell types in a multicellular organism

- A fertilized egg gives rise to many different cell types
- Cell types are organized successively into tissues, organs, organ systems, and the whole organism
- Gene expression orchestrates the developmental programs of animals

- Cell **differentiation** is the process by which cells become specialized in structure and function
- The physical processes that give an organism its shape constitute **morphogenesis**
- Differential gene expression results from genes being regulated differently in each cell type
- Materials in the egg can set up gene regulation that is carried out as cells divide

Cytoplasmic Determinants and Inductive Signals

- An egg's cytoplasm contains RNA, proteins, and other substances that are distributed unevenly in the unfertilized egg
- **Cytoplasmic determinants** are maternal substances in the egg that influence early development
- As the zygote divides by mitosis, the resulting cells contain different cytoplasmic determinants, which lead to different gene expression

- The other major source of developmental information is the environment around the cell, especially signals from nearby embryonic cells
- In the process called **induction**, signal molecules from embryonic cells cause transcriptional changes in nearby target cells
- Thus, interactions between cells induce differentiation of specialized cell types

Sequential Regulation of Gene Expression During Cellular Differentiation

- **Determination** commits a cell irreversibly to its final fate
- Determination precedes differentiation

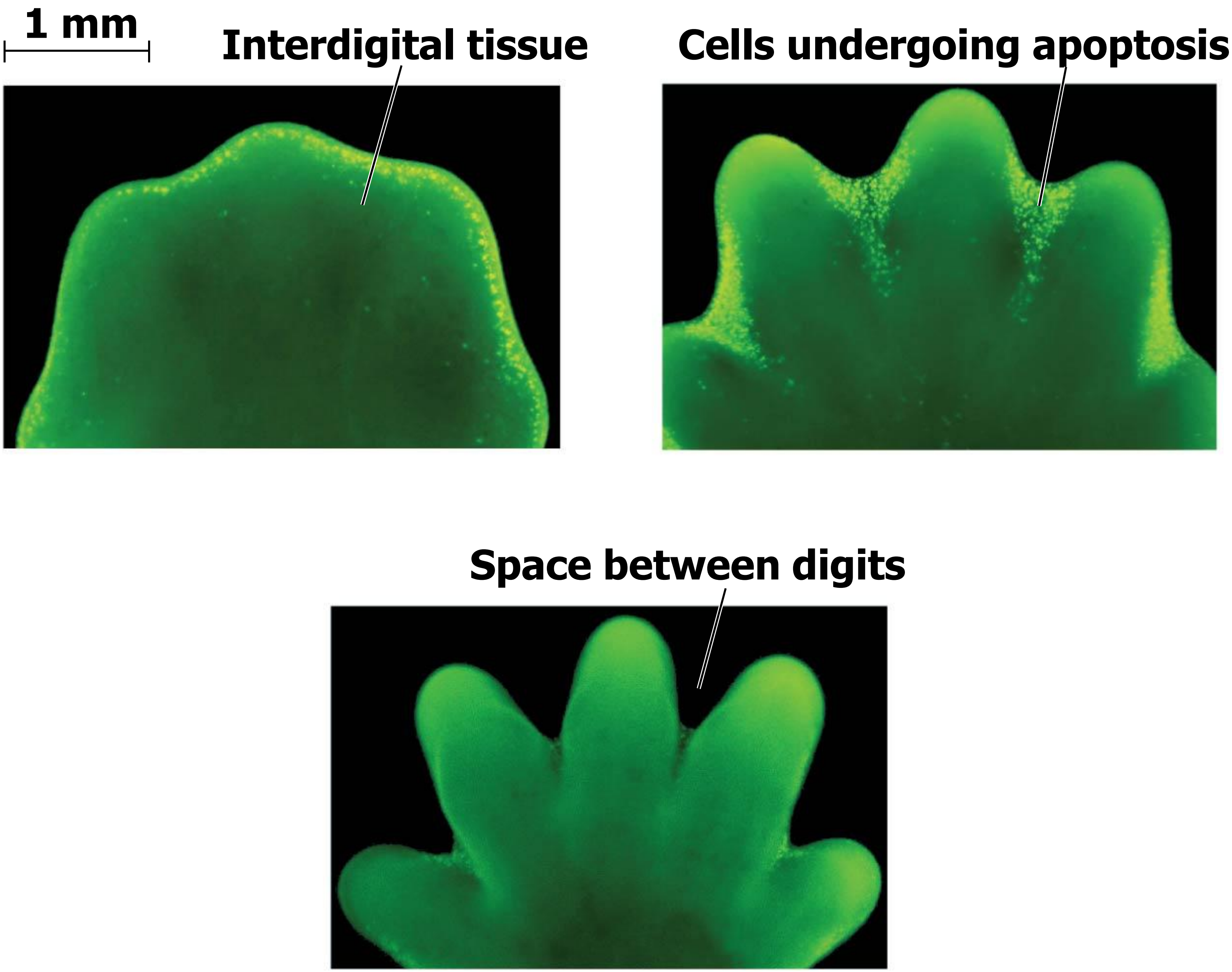
Apoptosis: A Type of Programmed Cell Death

- While most cells are differentiating in a developing organism, some are genetically programmed to die
- **Apoptosis** is the best-understood type of "programmed cell death"
- Apoptosis also occurs in the mature organism in cells that are infected, damaged, or at the end of their functional lives

- During apoptosis, DNA is broken up and organelles and other cytoplasmic components are fragmented
- The cell becomes multilobed and its contents are packaged up in vesicles
- These vesicles are then engulfed by scavenger cells
- Apoptosis protects neighboring cells from damage by nearby dying cells

- Apoptosis is essential to development and maintenance in all animals
- It is known to occur also in fungi and yeasts
- In vertebrates, apoptosis is essential for normal nervous system development and morphogenesis of hands and feet (or paws)

Figure 16.6

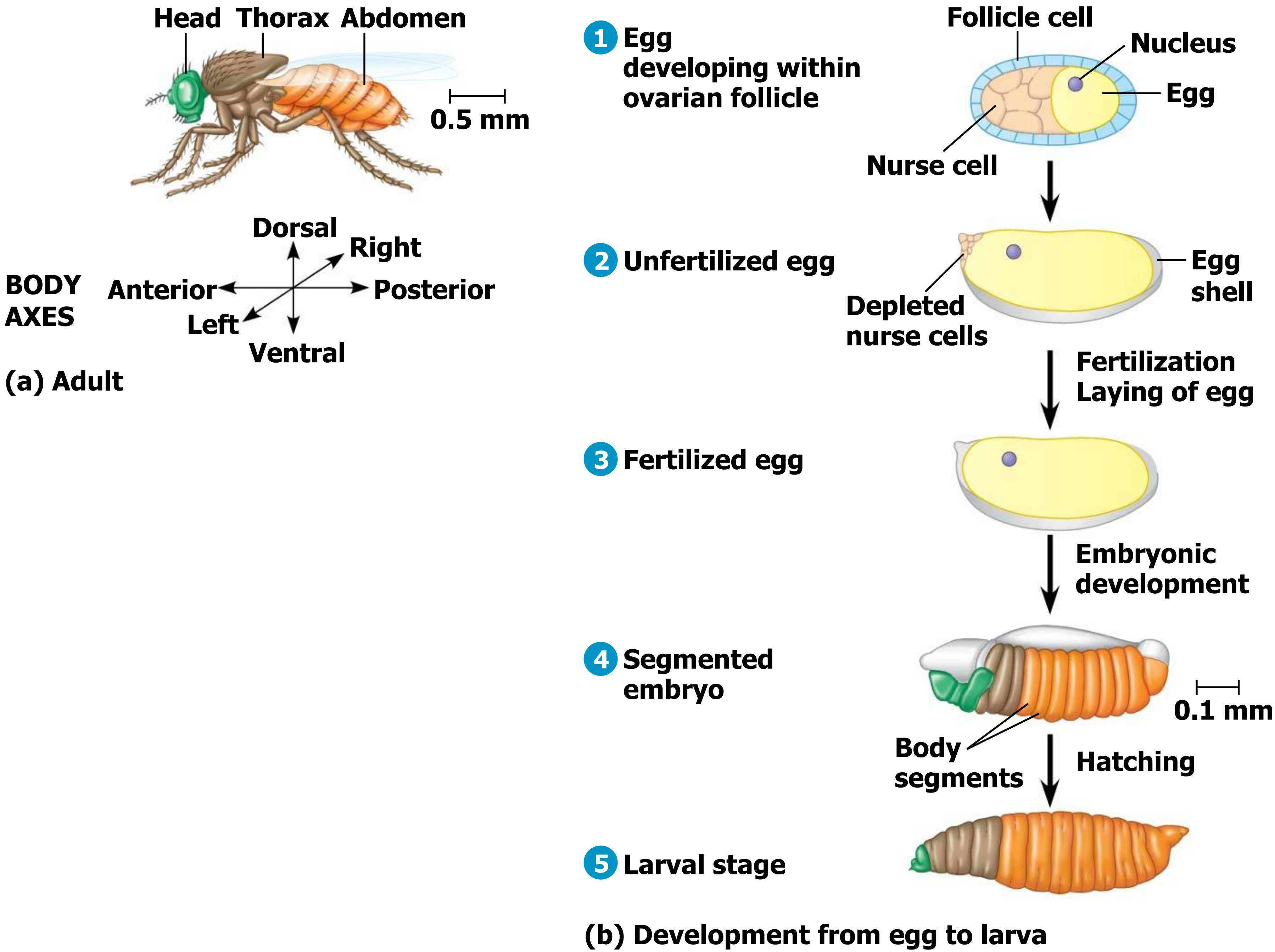

1 mm
Interdigital tissue
Cells undergoing apoptosis
Space between digits

Pattern Formation: Setting Up the Body Plan

- **Pattern formation** is the development of a spatial organization of tissues and organs
- In animals, pattern formation begins with the establishment of the major axes
- **Positional information**, the molecular cues that control pattern formation, tells a cell its location relative to the body axes and to neighboring cells

- Pattern formation has been extensively studied in the fruit fly *Drosophila melanogaster*
- Combining anatomical, genetic, and biochemical approaches, researchers have discovered developmental principles common to many other species, including humans

Figure 16.7



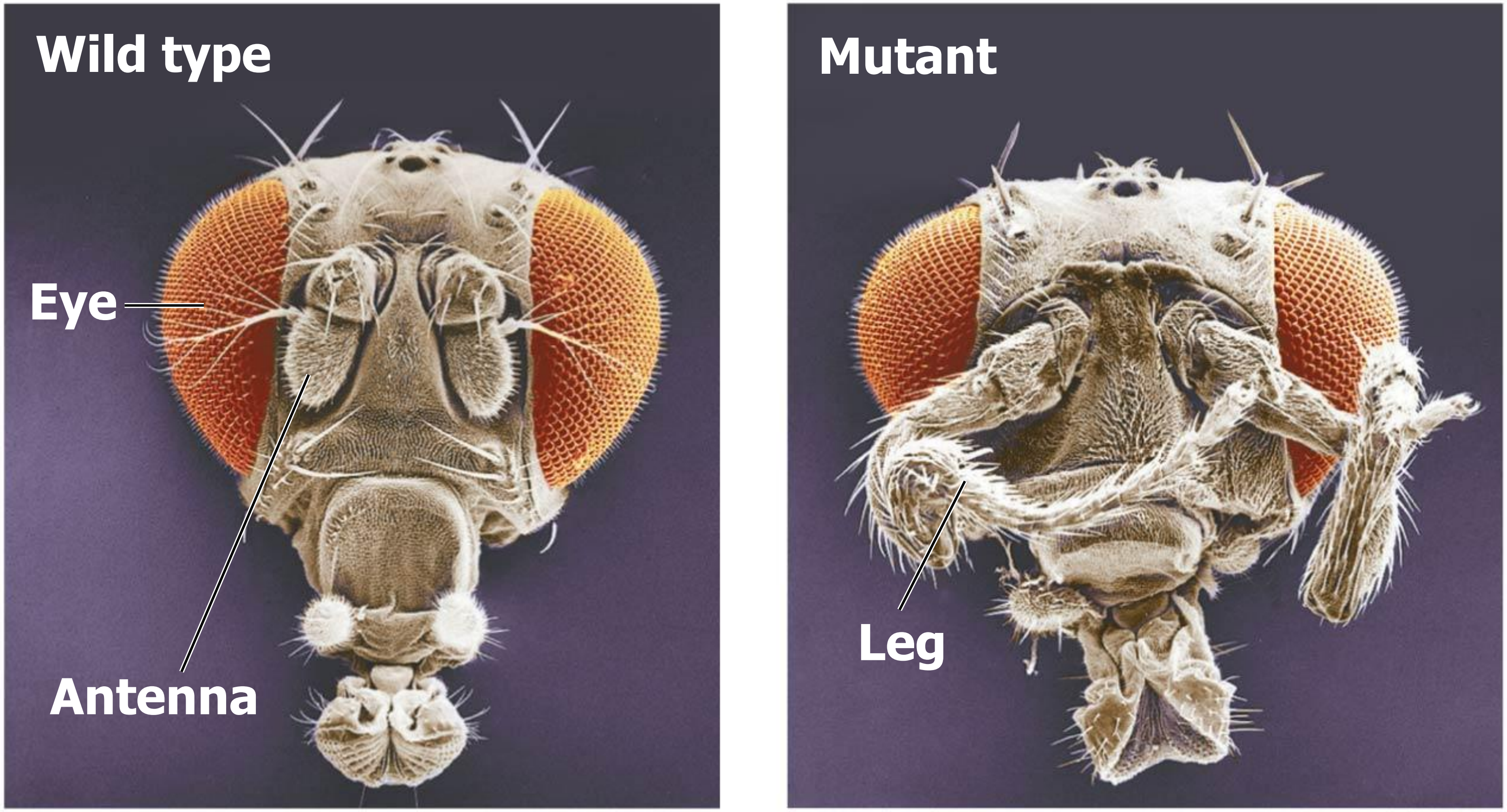
Head
Thorax
Abdomen
0.5 mm
BODY AXES
Dorsal
Right
Anterior
Posterior
Left
Ventral
(a) Adult
1 Egg developing within ovarian follicle
Follicle cell
Nucleus
Egg
Nurse cell
2 Unfertilized egg
Depleted nurse cells
Egg shell
Fertilization
Laying of egg
3 Fertilized egg
Embryonic development
4 Segmented embryo
0.1 mm
Body segments
Hatching
5 Larval stage
(b) Development from egg to larva

- The *Drosophila* eggs develop in the female’s ovary, surrounded by ovarian cells called nurse cells and follicle cells
- After fertilization, embryonic development results in a segmented larva, which goes through three stages
- Eventually the larva forms a cocoon within which it metamorphoses into an adult fly

Genetic Analysis of Early Development: *Scientific Inquiry*

- Edward B. Lewis, Christiane Nüsslein-Volhard, and Eric Wieschaus won a Nobel Prize in 1995 for decoding pattern formation in *Drosophila*
- Lewis discovered the **homeotic genes**, which control pattern formation in late embryo, larva, and adult stages

Figure 16.8



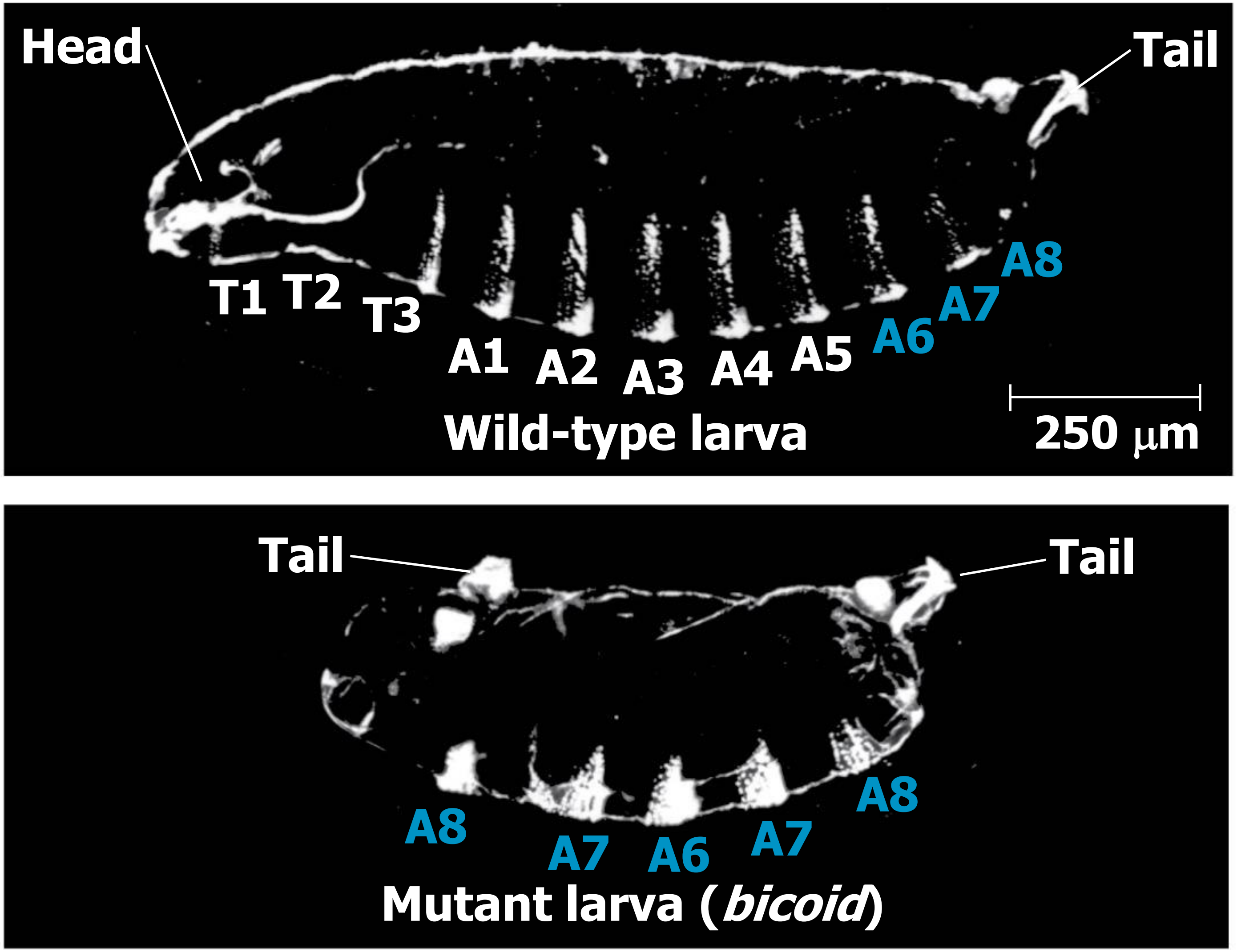
Axis Establishment

- **Maternal effect genes** encode cytoplasmic determinants that initially establish the axes of the body of *Drosophila*
- These maternal effect genes are also called **egg-polarity genes** because they control orientation of the egg and consequently the fly

Bicoid: A Morphogen Determining Head Structures

- One maternal effect gene, the ***bicoid*** gene, affects the front half of the body
- An embryo whose mother has no functional *bicoid* gene lacks the front half of its body and has duplicate posterior structures at both ends

Figure 16.9



Head
Tail
T1
T2
T3
A1
A2
A3
A4
A5
A6
A7
A8
Wild-type larva
250 μm
Tail
Tail
A8
A7
A6
A7
A8
Mutant larva (*bicoid*)

- This phenotype suggested that the product of the mother's *bicoid* gene is concentrated at the future anterior end and is required for setting up the anterior end of the fly
- This hypothesis is an example of the morphogen gradient hypothesis; gradients of substances called **morphogens** establish an embryo's axes and other features

- The *bicoid* mRNA is highly concentrated at the anterior end of the embryo
- After the egg is fertilized, the mRNA is translated into Bicoid protein, which diffuses from the anterior end
- The result is a gradient of Bicoid protein
- Injection of *bicoid* mRNA into various regions of an embryo results in the formation of anterior structures at the site of injection