Chapter 47

Animal Development

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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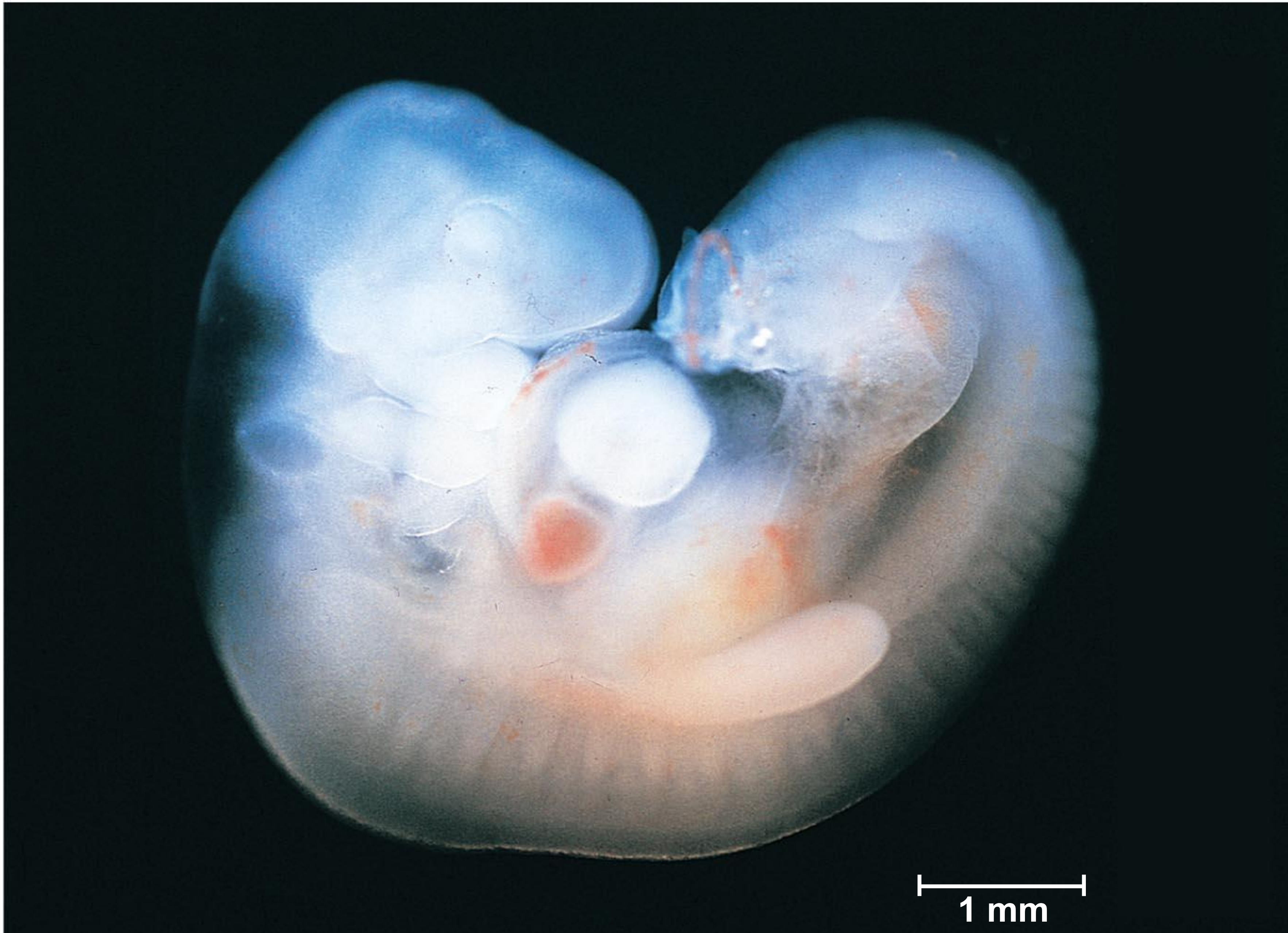
Overview: A Body-Building Plan

- It is difficult to imagine that each of us began life as a single cell (fertilized egg) called a zygote.
- A human embryo at about 6–8 weeks after conception shows development of distinctive features.

How did this complex embryo develop from a single fertilized egg?



- Development is determined by the zygote's genome and molecules in the egg cytoplasm called ***Cytoplasmic determinants*****.**
- ***Cell differentiation*** is the specialization of cells in structure and function.
- ***Morphogenesis*** is the process by which an animal takes shape / form.
- **Model organisms** are species that are representative of a larger group and easily studied. Classic embryological studies use the sea urchin, frog, chick, and the nematode *C. elegans.*

After **fertilization**, embryonic development proceeds through **cleavage**, **gastrulation**, and **organogenesis**

- Important events regulating development occur during fertilization and the three stages that build the animal's body
  - ***Cleavage***: cell division creates a hollow ball of cells called a blastula
  - ***Gastrulation***: cells are rearranged into a three-layered gastrula
  - ***Organogenesis***: the three germ layers interact and move to give rise to organs.

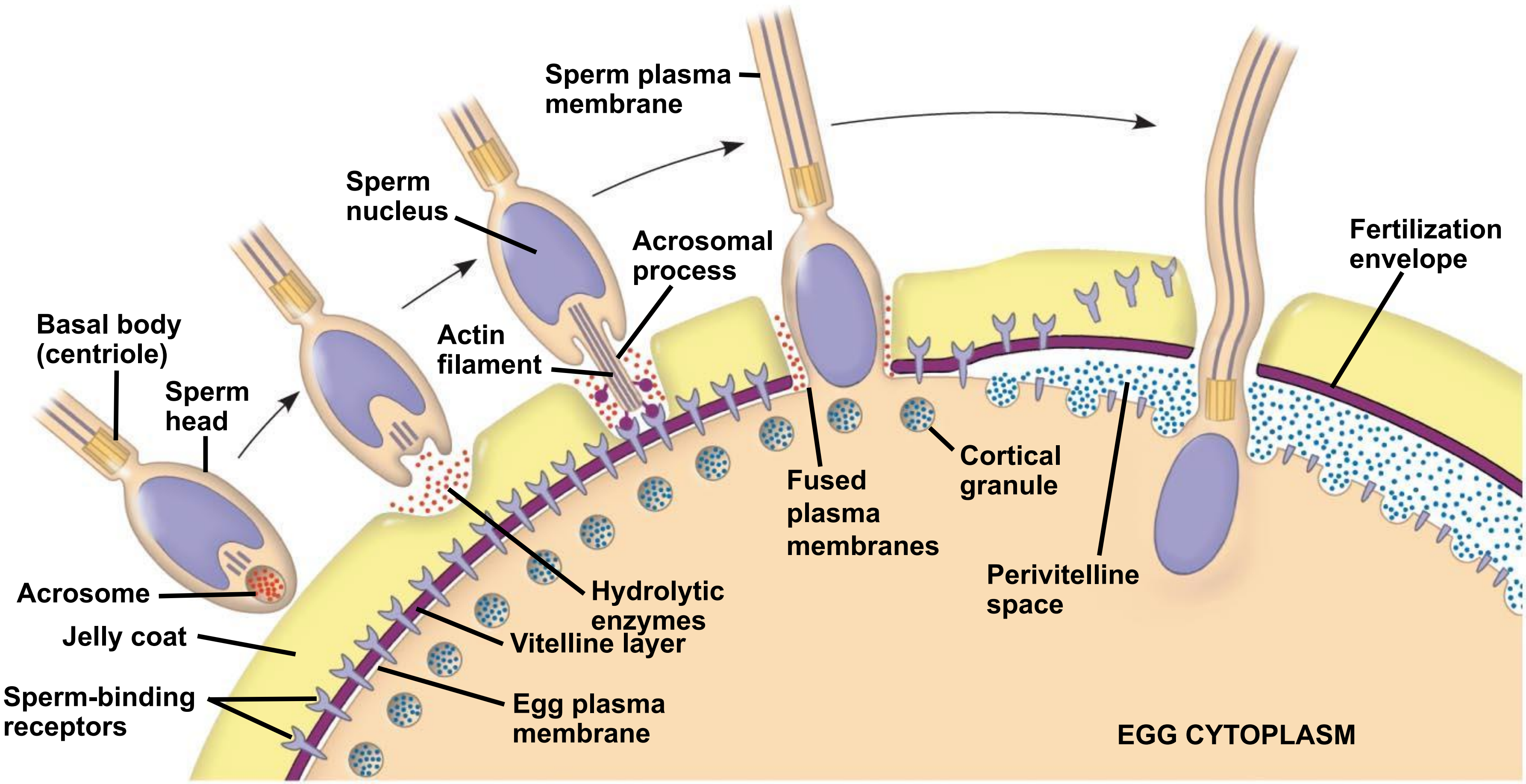
Fertilization: sperm + egg = zygote
n + n = 2n

- Fertilization brings the haploid nuclei of sperm and egg together, forming a diploid zygote.
- The sperm’s contact with the egg’s surface initiates metabolic reactions in the egg that trigger the onset of embryonic development:
    - Acrosomal Reaction
    - Cortical Reaction

The Acrosomal Reaction

- The ***acrosomal reaction*** is triggered when the sperm meets the egg.
- The *acrosome at the tip of the sperm releases hydrolytic enzymes that digest material surrounding the egg*.
- Gamete contact and/or fusion *depolarizes the egg cell membrane* and sets up a ***fast** block to polyspermy*.

The acrosomal and cortical reactions during sea urchin fertilization



The Cortical Reaction

- Fusion of egg and sperm also initiates the ***cortical reaction***:
- This reaction induces a *rise in* Ca^{2+} that stimulates *cortical granules* to release their contents outside the egg.
- These changes cause formation of a *fertilization envelope* that functions as a ***slow*** *block to polyspermy*.

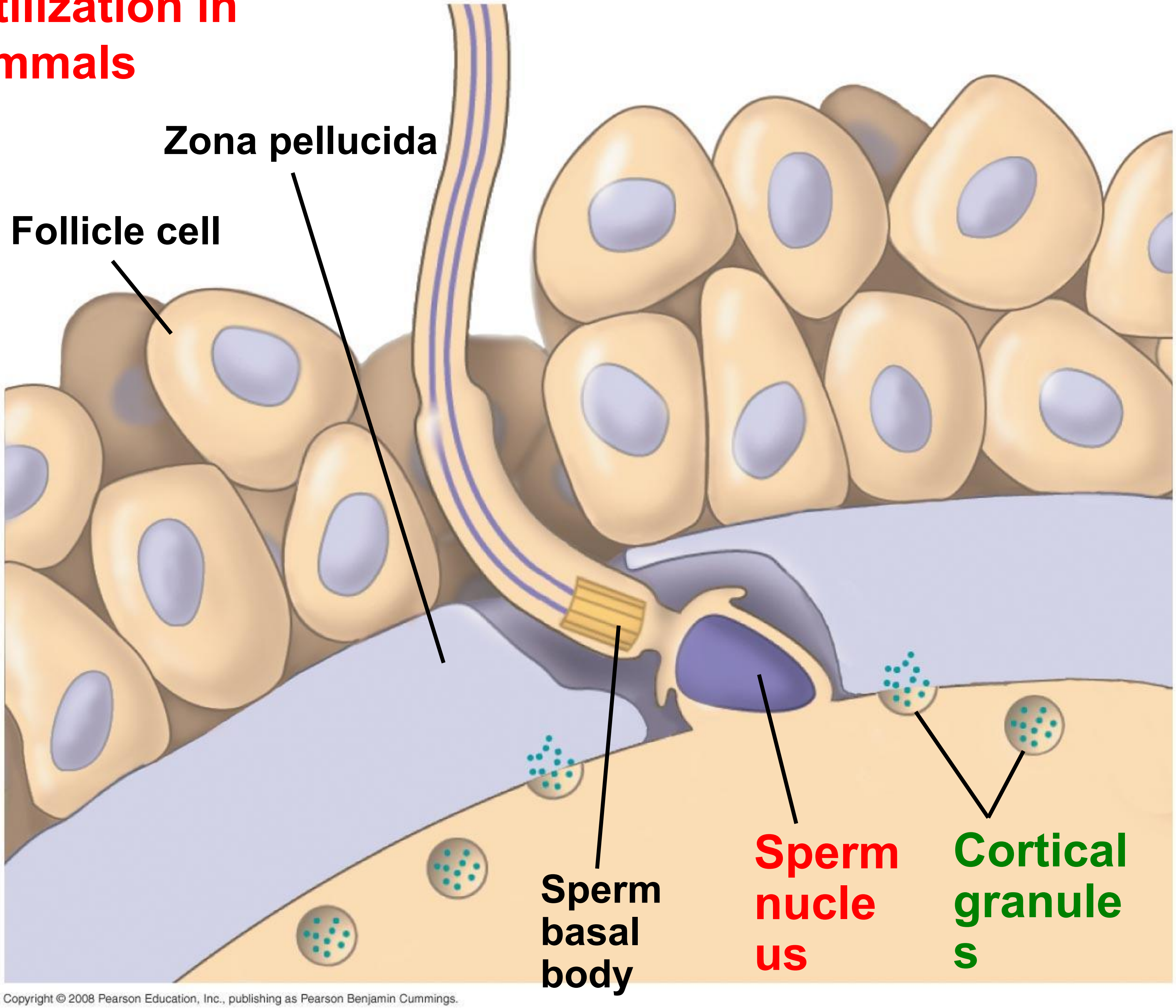
Activation of the Egg

- The *sharp rise in* Ca^{2+} in the *egg's cytosol* increases the rates of cellular respiration and protein synthesis by the egg cell.
- With these *rapid changes in metabolism*, the egg is said to be activated.
- The sperm nucleus merges with the egg nucleus and cell division begins.

Fertilization in Mammals

- Fertilization in mammals and other terrestrial animals is internal.
- In mammalian fertilization, the cortical reaction modifies the **zona pellucida**, the extracellular matrix of the egg, as a *slow block to polyspermy*.
- In mammals the first cell division occurs 12–36 hours after sperm binding.
- The diploid nucleus forms after this first division of the zygote.

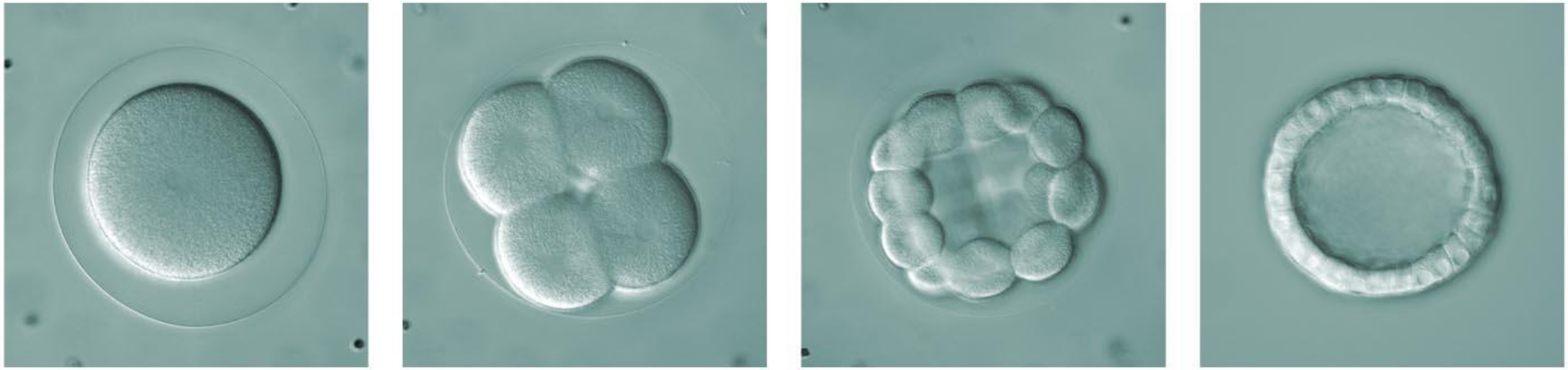
Fertilization in mammals



Cleavage = Rapid Mitosis / No Mass change

- 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 called **blastomeres.**
- The **blastula** is a ball of cells with a fluid-filled cavity called a **blastocoel.**

Cleavage in an echinoderm embryo

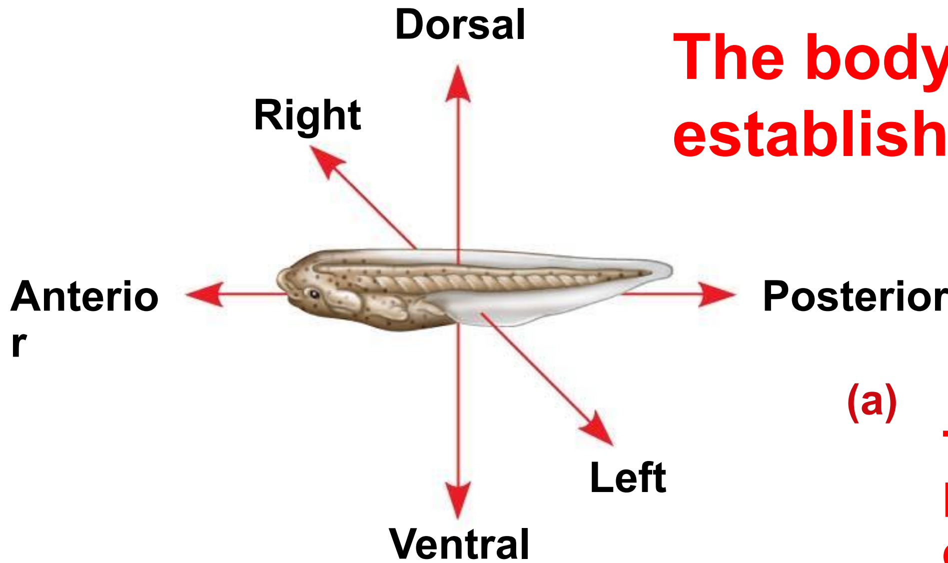


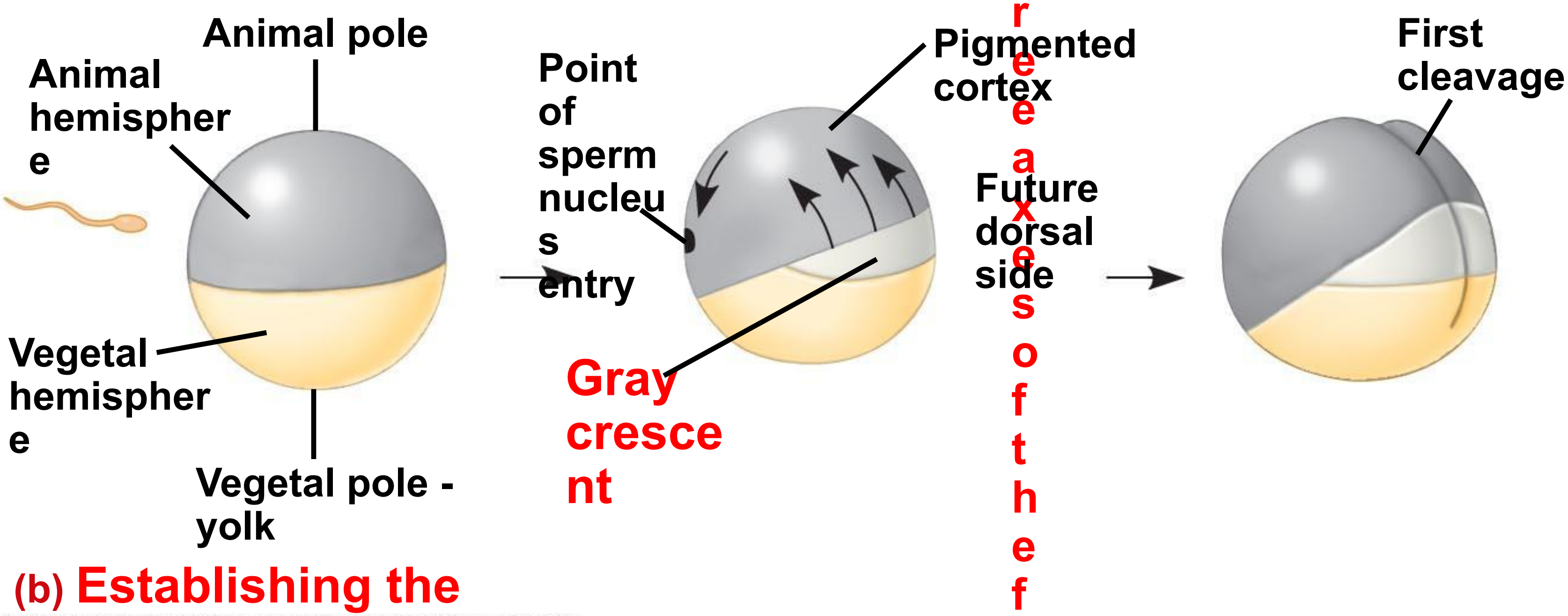
(a) Fertilized egg (b) Four-cell stage (c) Early blastula (d) Later blastula

- The eggs and zygotes of many animals, except mammals, have a definite polarity.
- The polarity is defined by distribution of **yolk** (stored nutrients).
- The **vegetal pole** has more yolk; the **animal pole** has less yolk.

- The three body axes are established by the egg's polarity and by a cortical rotation following binding of the sperm.
- Cortical rotation exposes a **gray crescent** opposite to the point of sperm entry.

The body axes and their establishment in an amphibian





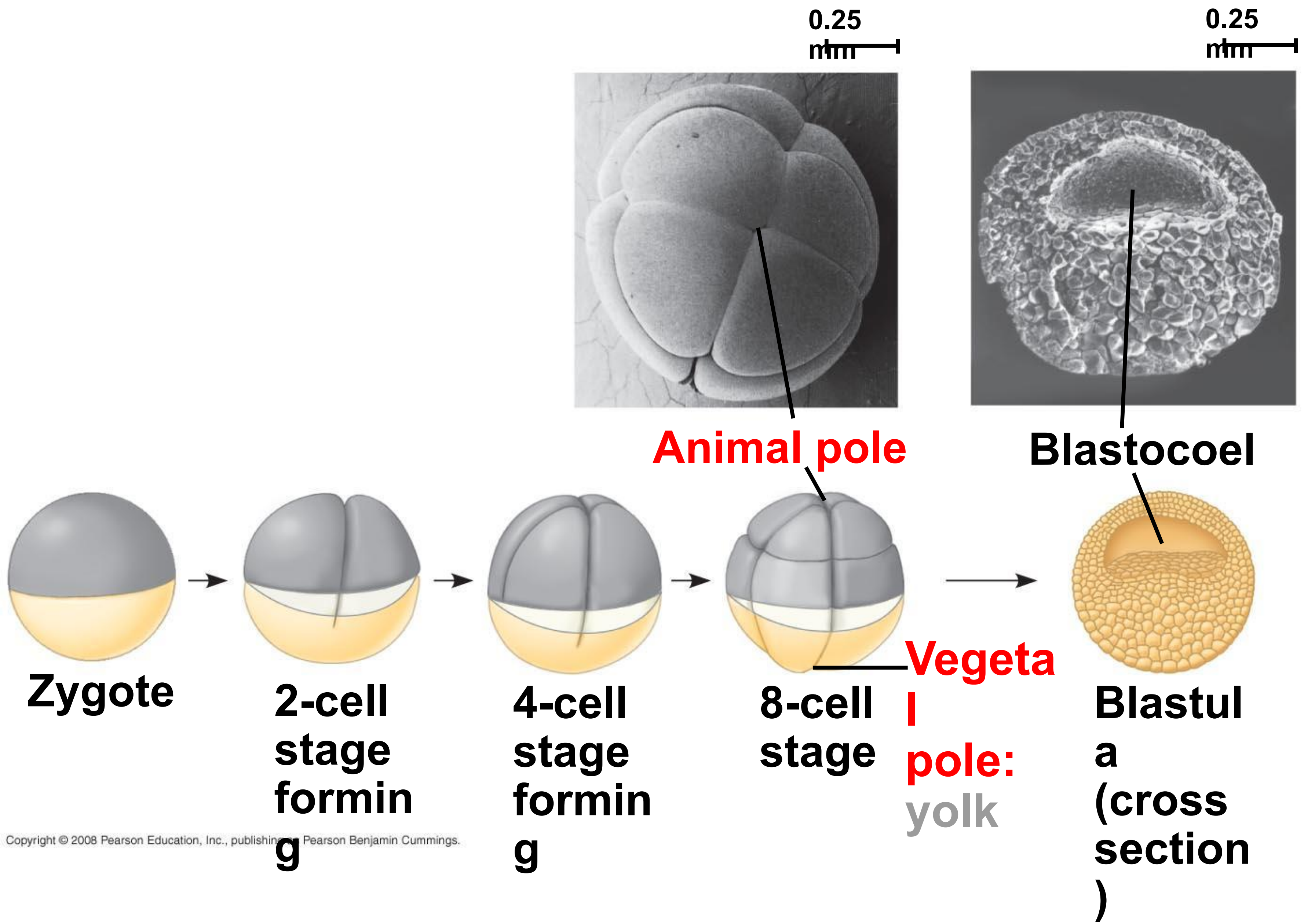
Gray crescent

The three axes of the fu

(b) Establishing the axes

- Cleavage planes usually follow a pattern that is relative to the zygote's animal and vegetal poles.
- Cell division is slowed by yolk. *Yolk can cause uneven cell division at the poles*.
- **Holoblastic cleavage**, complete division of the egg, occurs in species whose eggs have little or moderate amounts of yolk, such as sea urchins and frogs.
- **Meroblastic cleavage**, incomplete division of the egg, occurs in species with yolk-rich eggs, such as reptiles and birds.

Cleavage in a frog embryo



Gastrulation

- **Gastrulation** rearranges the cells of a blastula into a three-layered embryo, called a **gastrula**, which has a primitive gut.
- The three layers produced by gastrulation are called embryonic **germ layers**:
  - The **ectoderm** forms the outer layer
  - The **endoderm** lines the digestive tract
  - The **mesoderm** partly fills the space between the endoderm and ectoderm.

Gastrulation in the sea urchin embryo:

The blastula consists of a single layer of cells surrounding the blastocoel.

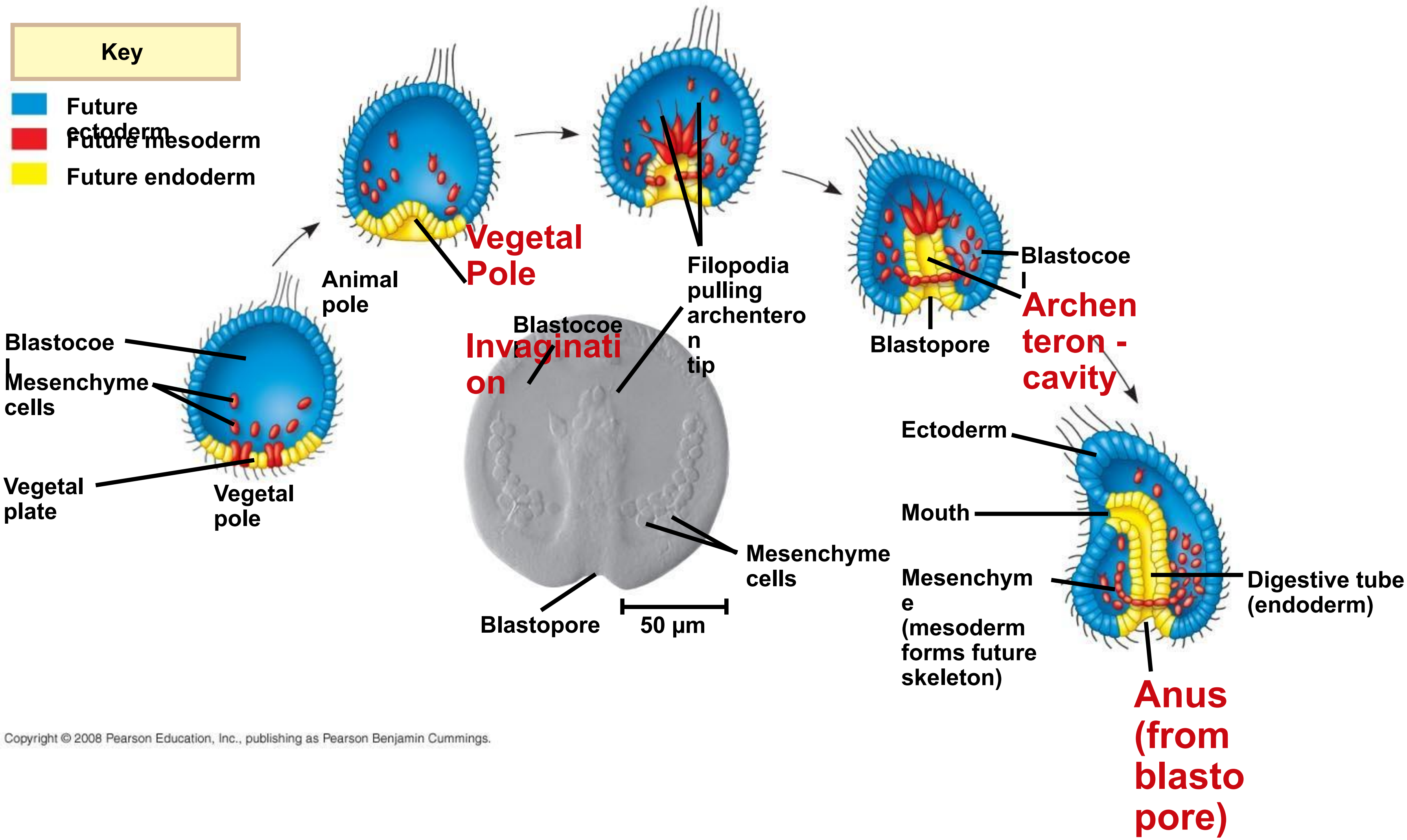
Mesenchyme cells migrate from the vegetal pole into the blastocoel.

The vegetal plate forms from the remaining cells of the vegetal pole and buckles inward through **invagination.**

The newly formed cavity is called the **archenteron.**

This opens through the **blastopore**, which will become the anus.

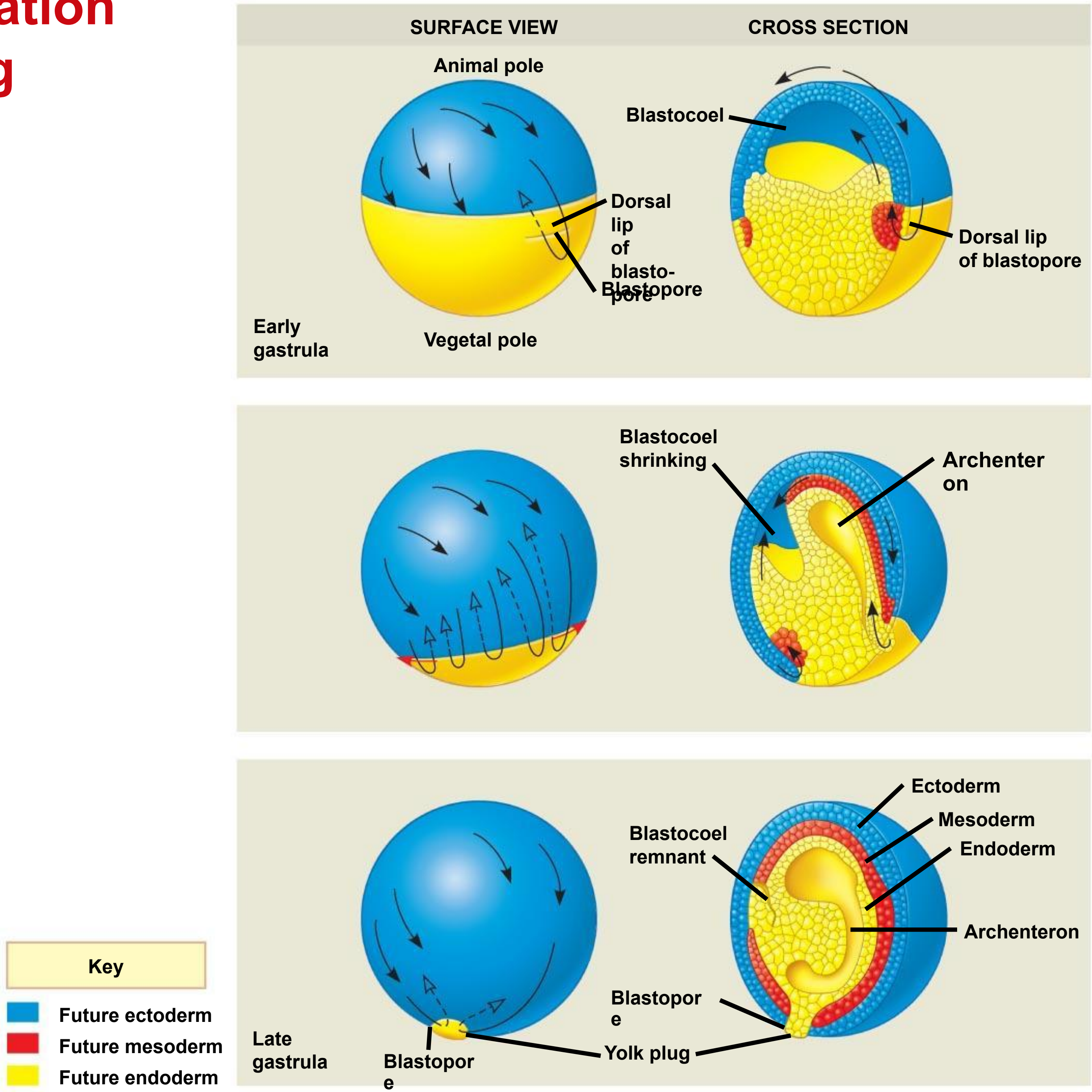
Gastrulation in a sea urchin embryo



Gastrulation in the frog

- The frog blastula is many cell layers thick. Cells of the **dorsal lip** originate in the gray crescent and invaginate to create the archenteron.
- Cells continue to move from the embryo surface into the embryo by **involution.** These cells become the endoderm and mesoderm.
  - The blastopore encircles a **yolk plug** when gastrulation is completed.
  - The surface of the embryo is now ectoderm, the innermost layer is endoderm, and the middle layer is mesoderm.

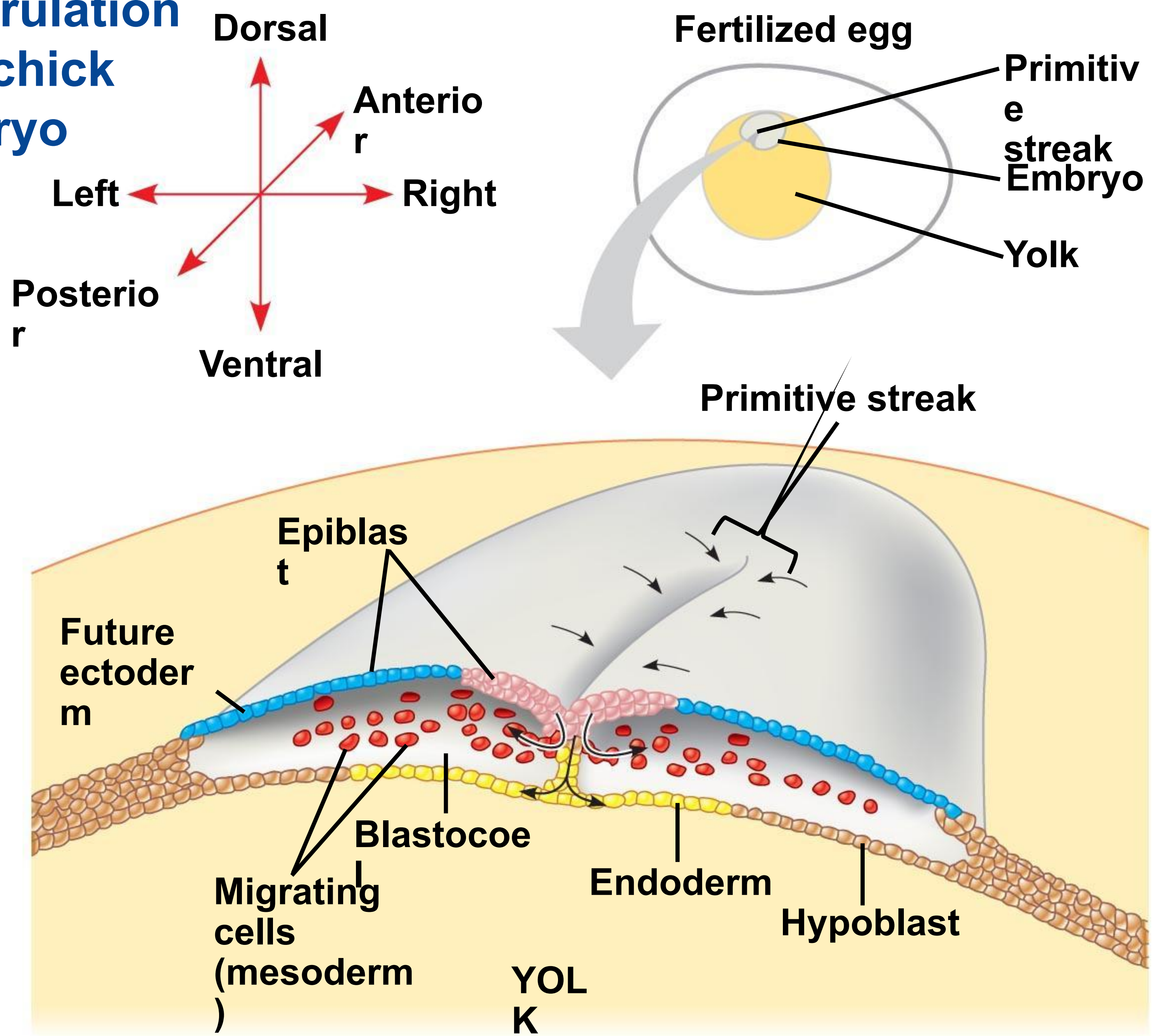
Gastrulation in a frog embryo



Gastrulation in the chick

- The embryo forms from a blastoderm and sits on top of a large yolk mass.
- During gastrulation, the upper layer of the blastoderm (epiblast) moves toward the midline of the blastoderm and then into the embryo toward the yolk.
- The midline thickens and is called the **primitive streak**.
- The movement of different epiblast cells gives rise to the endoderm, mesoderm, and ectoderm.

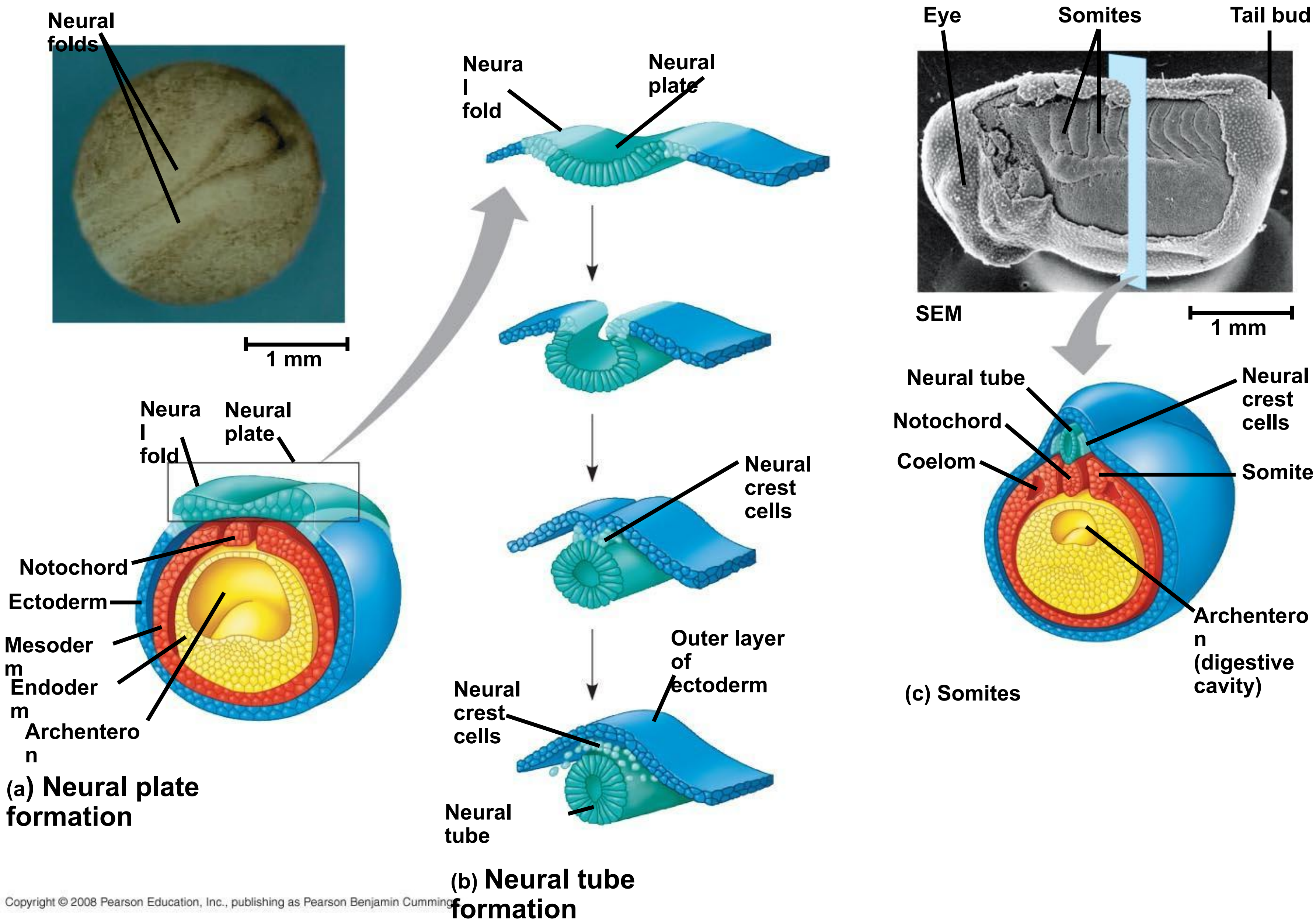
Gastrulation in a chick embryo



Organogenesis

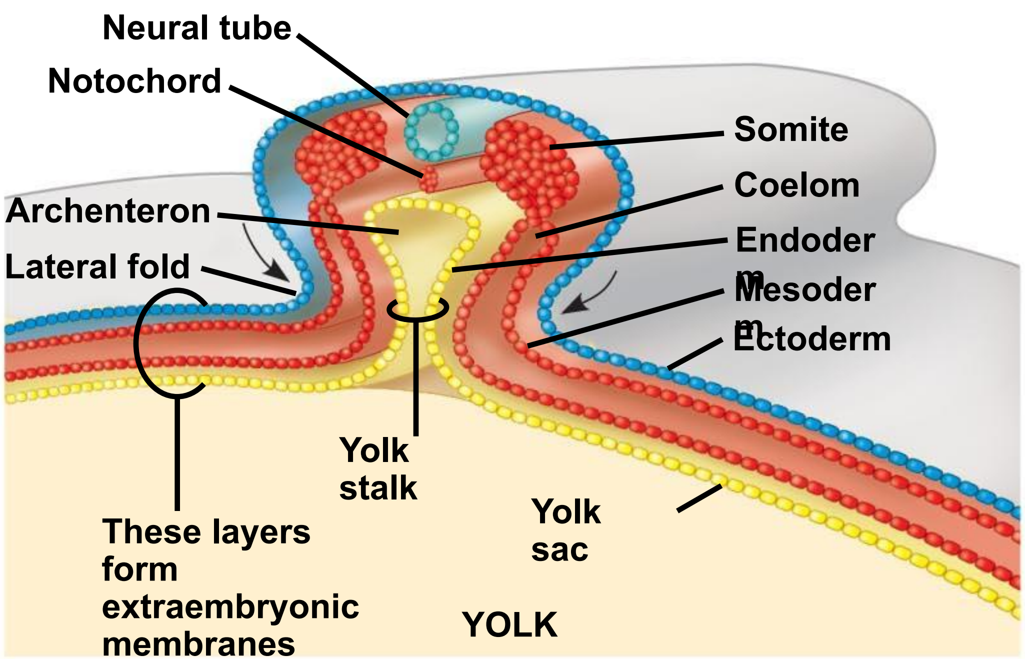
- During **organogenesis**, various regions of the germ layers develop into rudimentary organs.
- The frog is used as a model for organogenesis.
- Early in vertebrate organogenesis, the ***notochord*** forms from mesoderm, and the ***neural plate*** forms from ectoderm.

Early organogenesis in a frog embryo

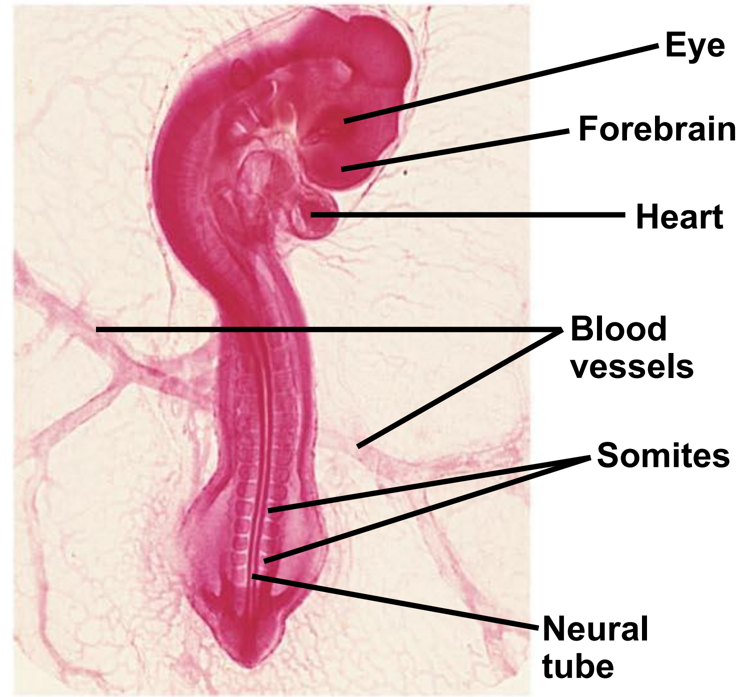


- The neural plate soon curves inward, forming the **neural tube.** The neural tube will become the central nervous system = brain and spinal cord.
- **Neural crest cells** develop along the neural tube of vertebrates and form various parts of the embryo: nerves, parts of teeth, skull bones ...
- Mesoderm lateral to the notochord forms blocks called **somites.**
- Lateral to the somites, the *mesoderm splits to form the coelom*.

Organogenesis in a chick embryo is similar to that in a frog



(a) Early organogenesis



(b) Late organogenesis

Adult derivatives of the three embryonic germ layers in vertebrates

ECTODERM

- Epidermis of skin and
  its
  derivatives (including
- sweat
  glands, hair follicles)
- Epithelial lining of
- mouth
- and anus
  Cornea and lens of eye
- Nervous system
- Sensory receptors in
- epidermis
  Adrenal medulla
  Tooth enamel
  Epithelium of pineal and
  pituitary glands

MESODERM

- Notochord
- Skeletal system
- Muscular system
- Muscular layer of
  stomach and intestine
- Excretory system
- Circulatory and lymphatic
  systems
- Reproductive system
  (except germ cells)
- Dermis of skin
- Lining of body cavity
- Adrenal cortex

ENDODERM

- Epithelial lining of
  digestive tract
- Epithelial lining of
  respiratory system
- Lining of urethra,
  urinary
  bladder, and
- reproductive
- system
- Liver
- Pancreas
  Thymus
  Thyroid and parathyroid
  glands

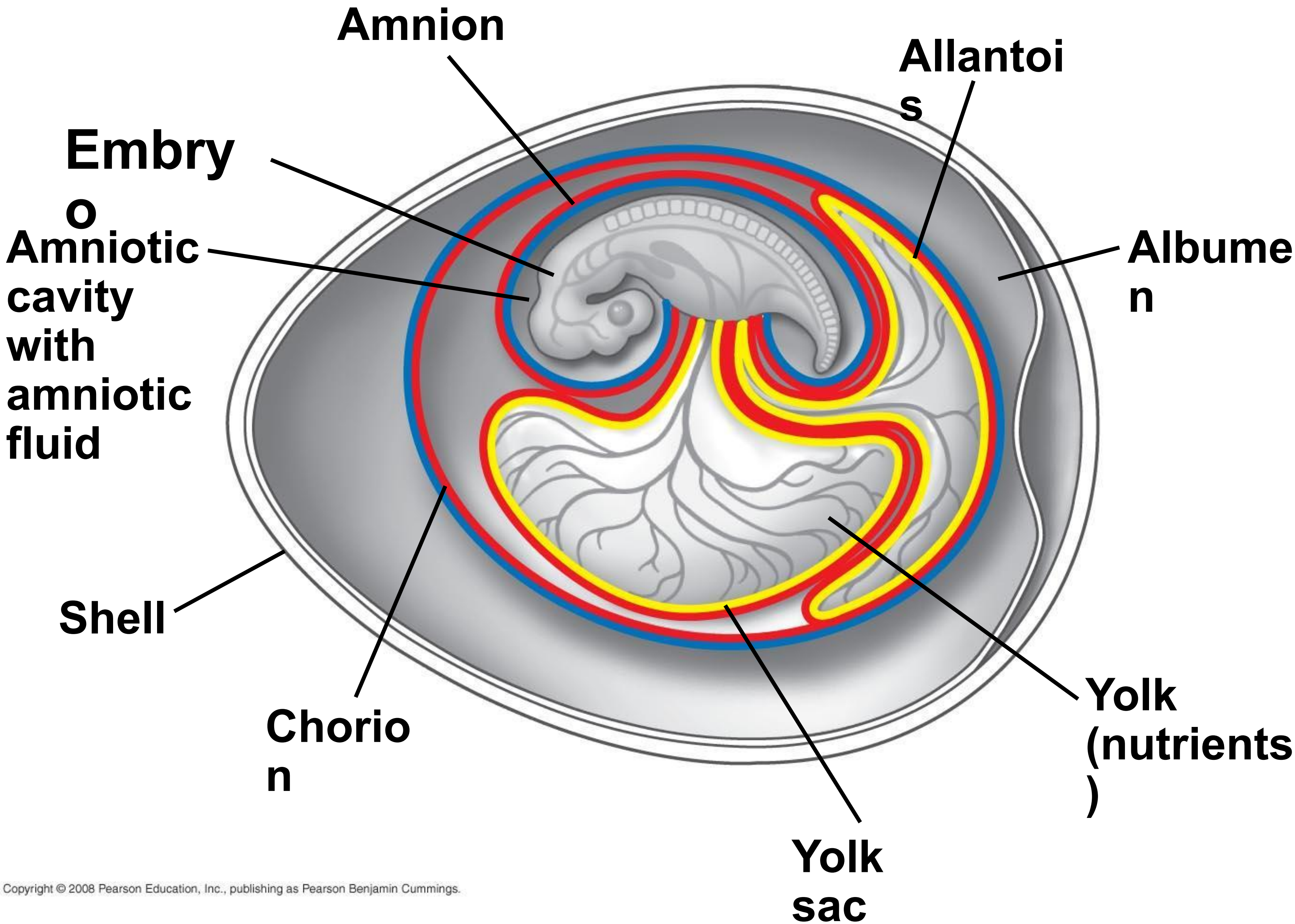
Developmental Adaptations of Amniotes

- Embryos of birds, other reptiles, and mammals develop in a fluid-filled sac in a shell or the uterus.
- Organisms with these adaptations are called **amniotes**.
- Amniotes develop extra-embryonic membranes to support the embryo.

Amniote ExtraEmbryonic Membranes

- During amniote development, four **extraembryonic membranes** form around the embryo:
  - The **chorion** *outermost membrane* / functions in gas exchange.
  - The **amnion** encloses the *amniotic fluid*.
  - The **yolk sac** encloses the yolk.
  - The **allantois** disposes of *nitrogenous waste* products and contributes to *gas exchange*.

ExtraEmbryonic Membranes in birds and other reptiles:

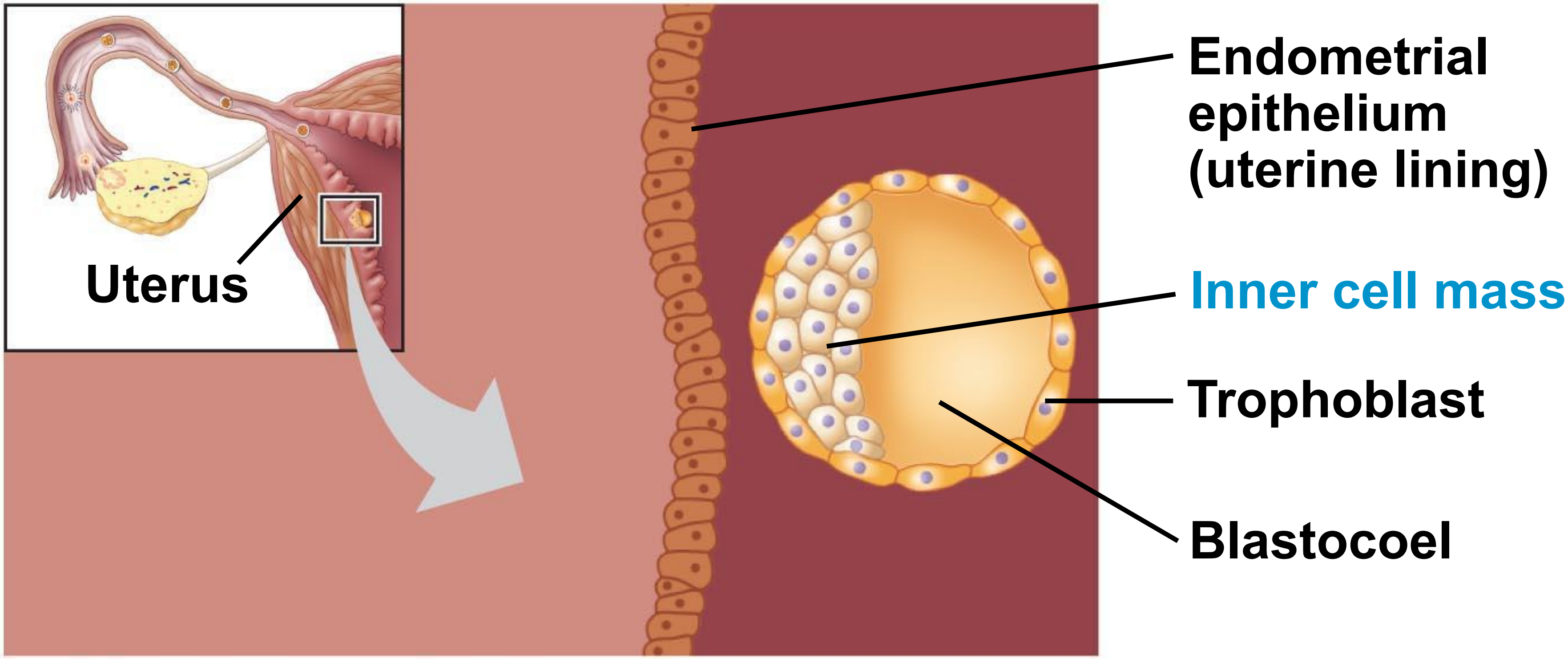


Mammalian Development

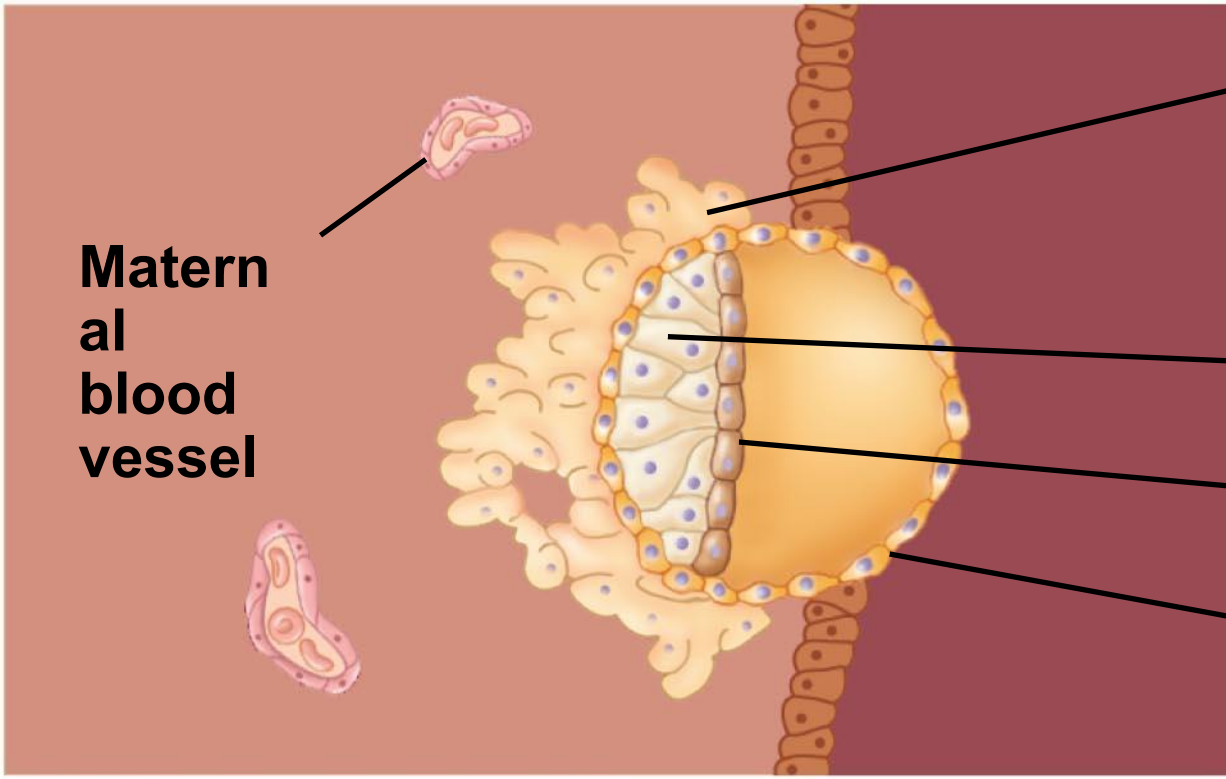
- The eggs of placental mammals
  - Are small yolk and store few nutrients
  - Exhibit holoblastic cleavage
  - Show no obvious polarity.
- Gastrulation and organogenesis resemble the processes in birds and other reptiles.
- Early cleavage is relatively slow in humans and other mammals.

- At completion of cleavage, the **blastocyst** forms.
- A group of cells called the **inner cell mass** develops into the embryo and forms the extraembryonic membranes.
- The **trophoblast**, the outer epithelium of the blastocyst, initiates implantation in the uterus, and the inner cell mass of the blastocyst forms a flat disk of cells.
- As implantation is completed, gastrulation begins.

Early embryonic development of a human



Early embryonic development of a human



Matern
al
blood
vessel

Expanding
region of
trophoblast

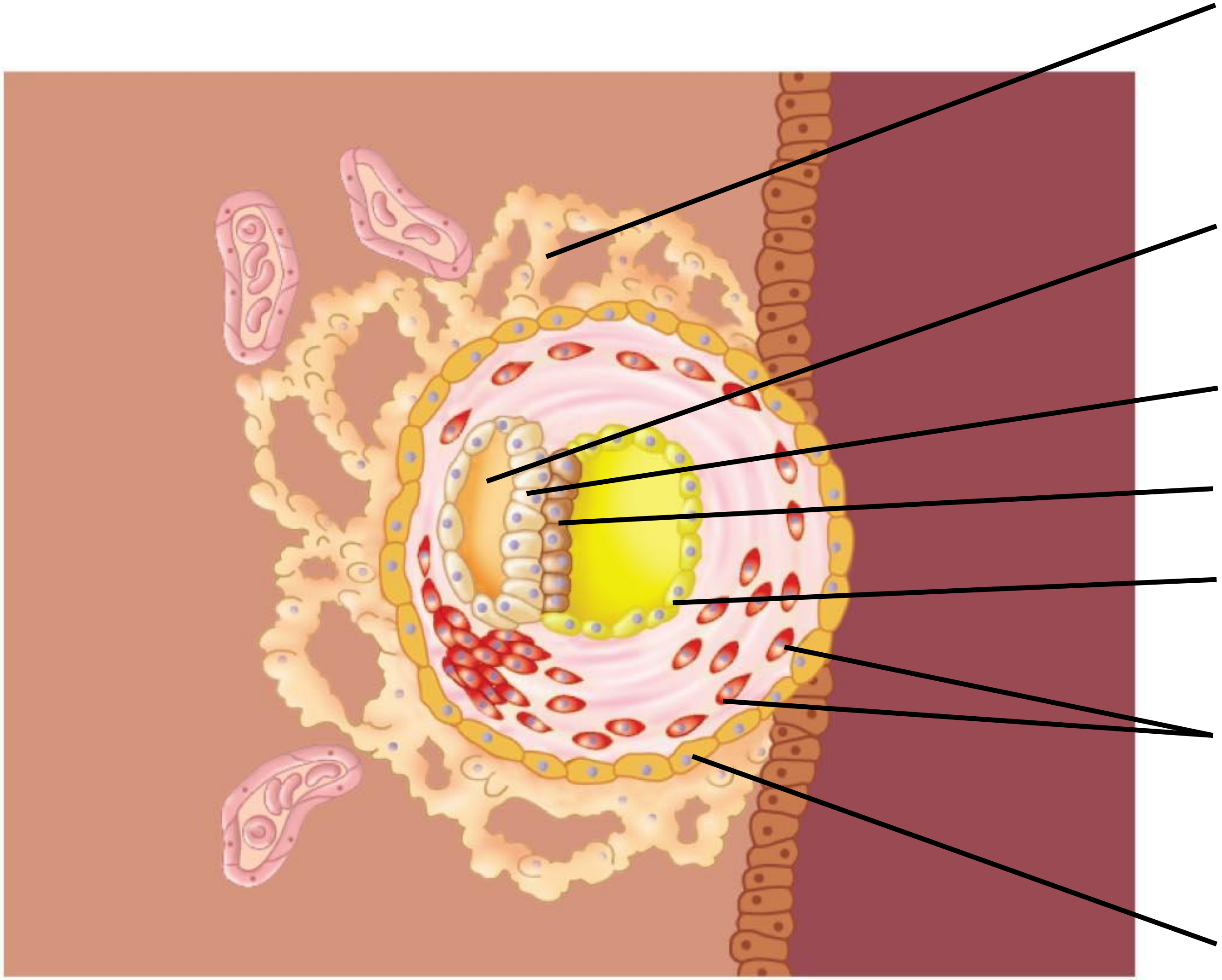
Epiblast

Hypoblast

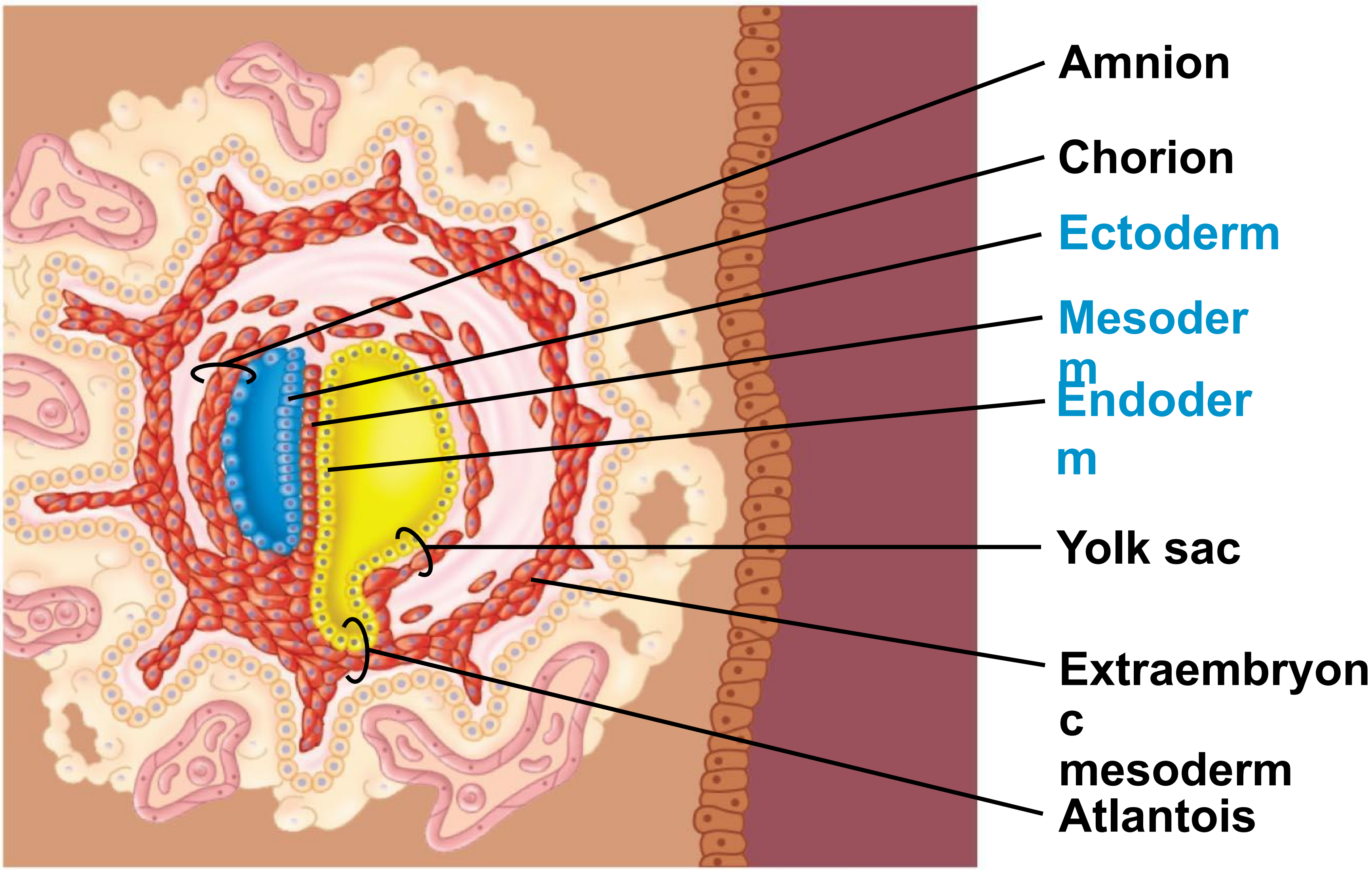
Trophobl
ast

- The epiblast cells invaginate through a primitive streak to form mesoderm and endoderm.
- The placenta is formed from the trophoblast, mesodermal cells from the epiblast, and adjacent endometrial tissue.
- The placenta allows for the exchange of materials between the mother and embryo.
- *By the end of gastrulation, the embryonic germ layers have formed*. The extraembryonic membranes in mammals are homologous to those of birds and other reptiles and develop in a similar way.

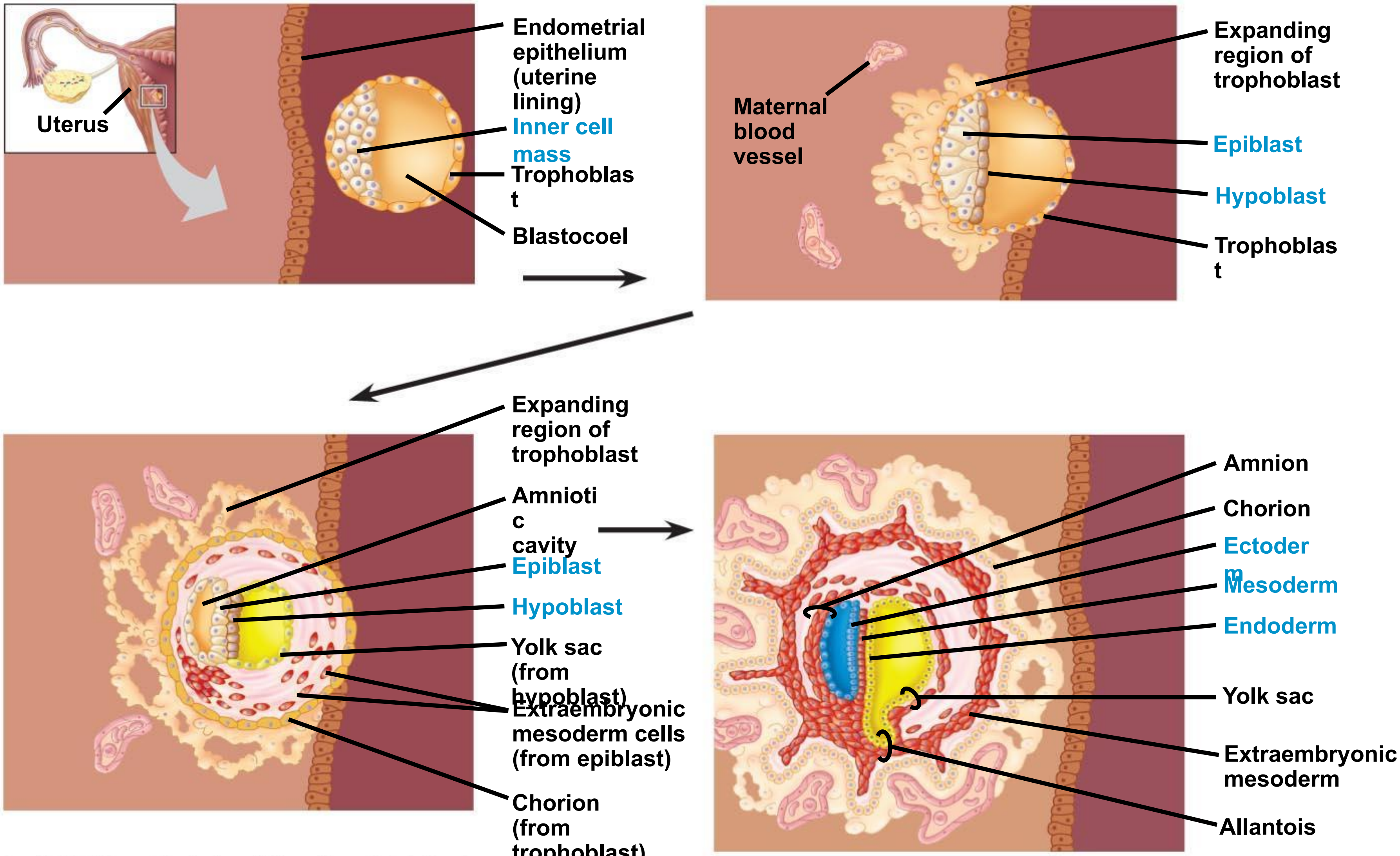
Early embryonic development of a human



Early embryonic development of a human



Four stages in early embryonic development of a human



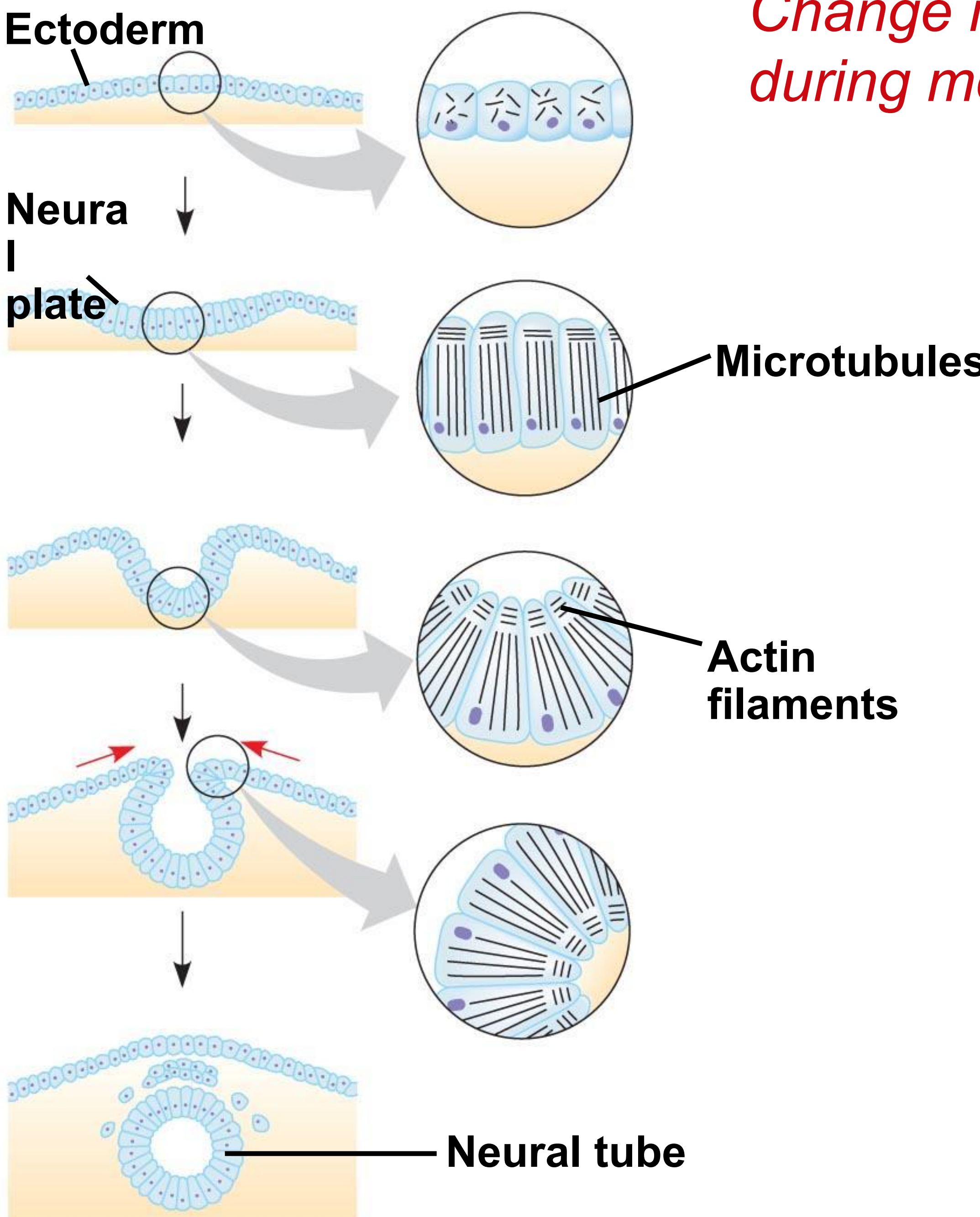
Morphogenesis* in animals involves specific *changes in cell shape*, *position*, *and adhesion

- Morphogenesis is a major aspect of development in plants and animals.
- *Only in animals does it involve the movement of cells*.

The Cytoskeleton, Cell Motility, and Convergent Extension

- Changes in cell shape usually involve reorganization of the cytoskeleton.
- Microtubules and microfilaments affect formation of the neural tube.

Change in cell shape during morphogenesis



- The cytoskeleton also drives cell migration, or cell crawling, the active movement of cells.
- *In gastrulation, tissue invagination is caused by changes in cell shape and migration*.
- Cell crawling is involved in **convergent extension**, a morphogenetic movement in which cells of a tissue become narrower and longer.

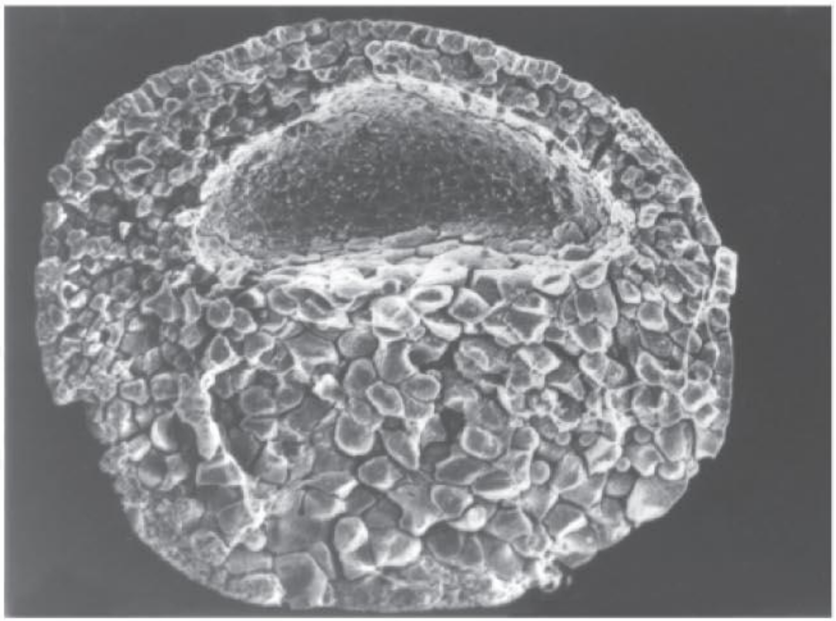
Role of Cell Adhesion Molecules and the Extracellular Matrix

- **Cell adhesion molecules** located on cell surfaces contribute to cell migration and stable tissue structure.
- One class of cell-to-cell adhesion molecule is the **cadherins**, which are important in formation of the frog blastula.

Cadherin is required for development of the blastula

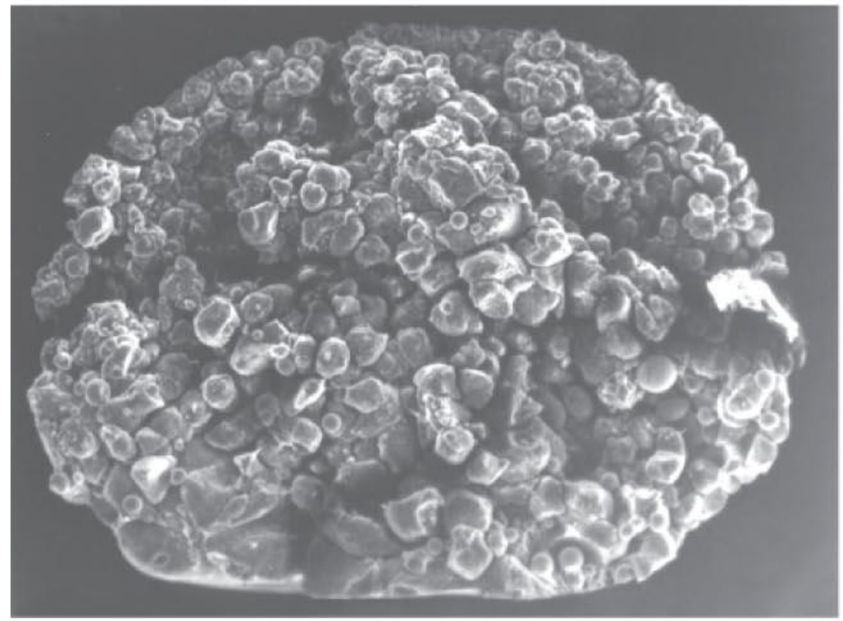
RESULTS

0.25 mm



Control embryo

0.25 mm



Embryo without EP cadherin

The developmental fate of cells depends on their history and on *inductive signals*

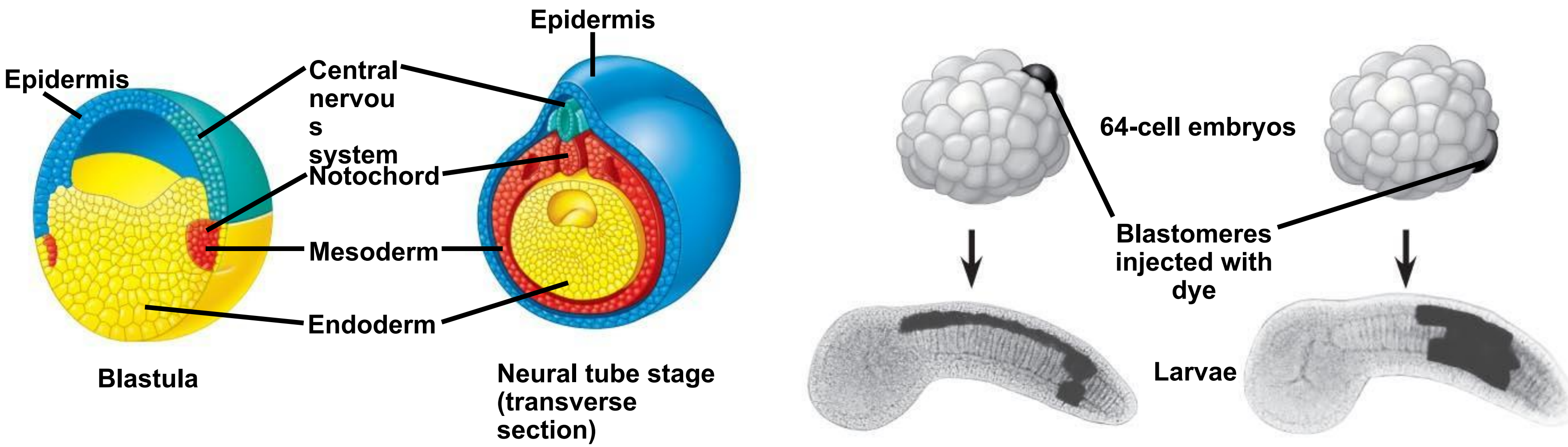
- Cells in a multicellular organism share the *same genome*.
- Differences in cell types is the result of differentiation, the expression of different genes = *differential gene expression*.

Two general principles underlie differentiation

1. During early cleavage divisions, embryonic cells must become different from one another.
   - *If the egg's cytoplasm is heterogenous, dividing cells vary in the* ***cytoplasmic determinants*** *they contain.*
2. After cell asymmetries are set up, *interactions among embryonic cells influence* their fate, usually causing changes in *gene expression*
   - This mechanism is called ***induction***, and is *mediated by diffusible chemicals or cell-cell interactions*.

- **Fate maps** are general territorial diagrams of embryonic development.
- Classic studies using frogs indicated that cell lineage in germ layers is traceable to blastula cells.
- To understand how embryonic cells acquire their fates, think about how basic axes of the embryo are established.

Fate Mapping for two chordates



(a) Fate map of a frog embryo

(b) Cell lineage analysis in a tunicate

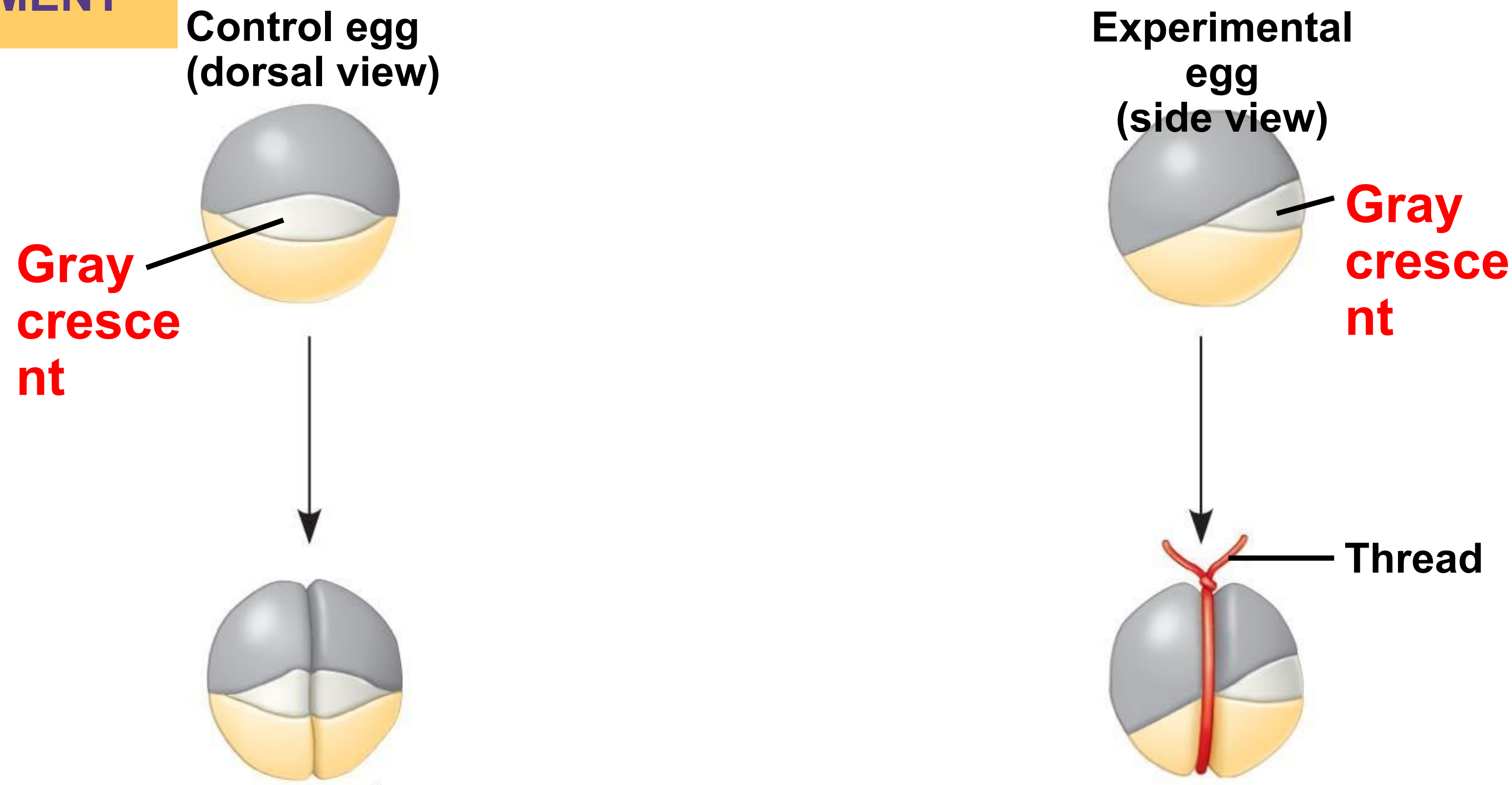
The Axes of the Basic Body Plan

- In nonamniotic vertebrates, basic instructions for establishing the body axes are set down early during oogenesis, or fertilization.
- In amniotes, local environmental differences play the major role in establishing initial differences between cells and the body axes.
- In many species that have cytoplasmic determinants, only the zygote is **totipotent.**
- That is, only the zygote can develop into all the cell types in the adult.

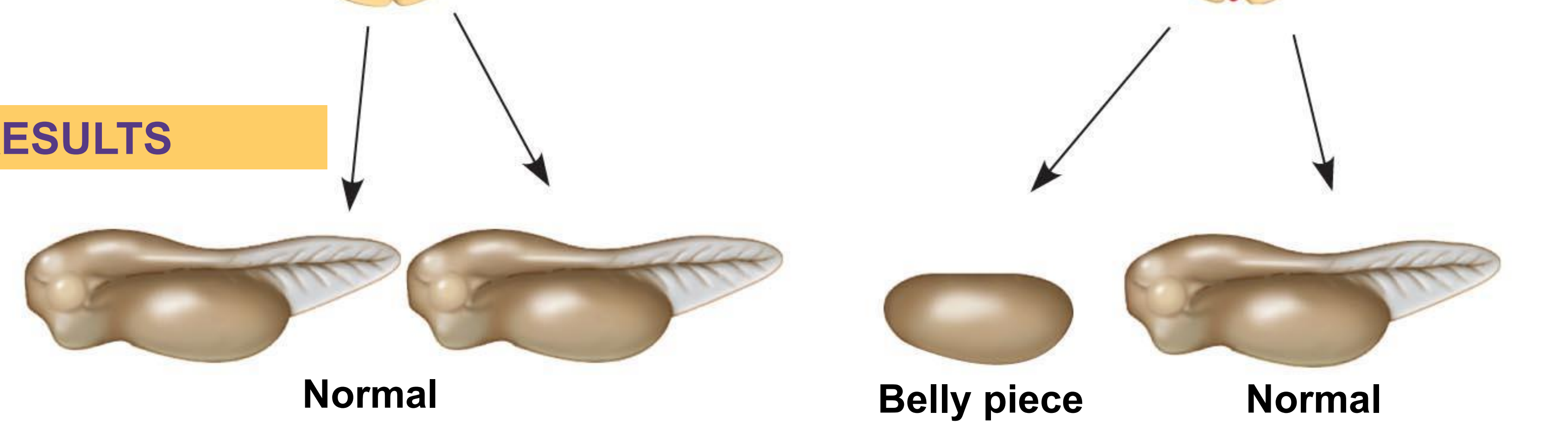
- Unevenly distributed ***cytoplasmic determinants*** in the egg cell help establish the body axes.
- These determinants set up differences in blastomeres resulting from cleavage.
- As embryonic development proceeds, potency of cells becomes more limited.
- After embryonic cell division creates cells that differ from each other, the cells begin to influence each other's fates by ***induction signals***.

How does distribution of the gray crescent affect the development potential of the two daughter cells?

EXPERIMENT



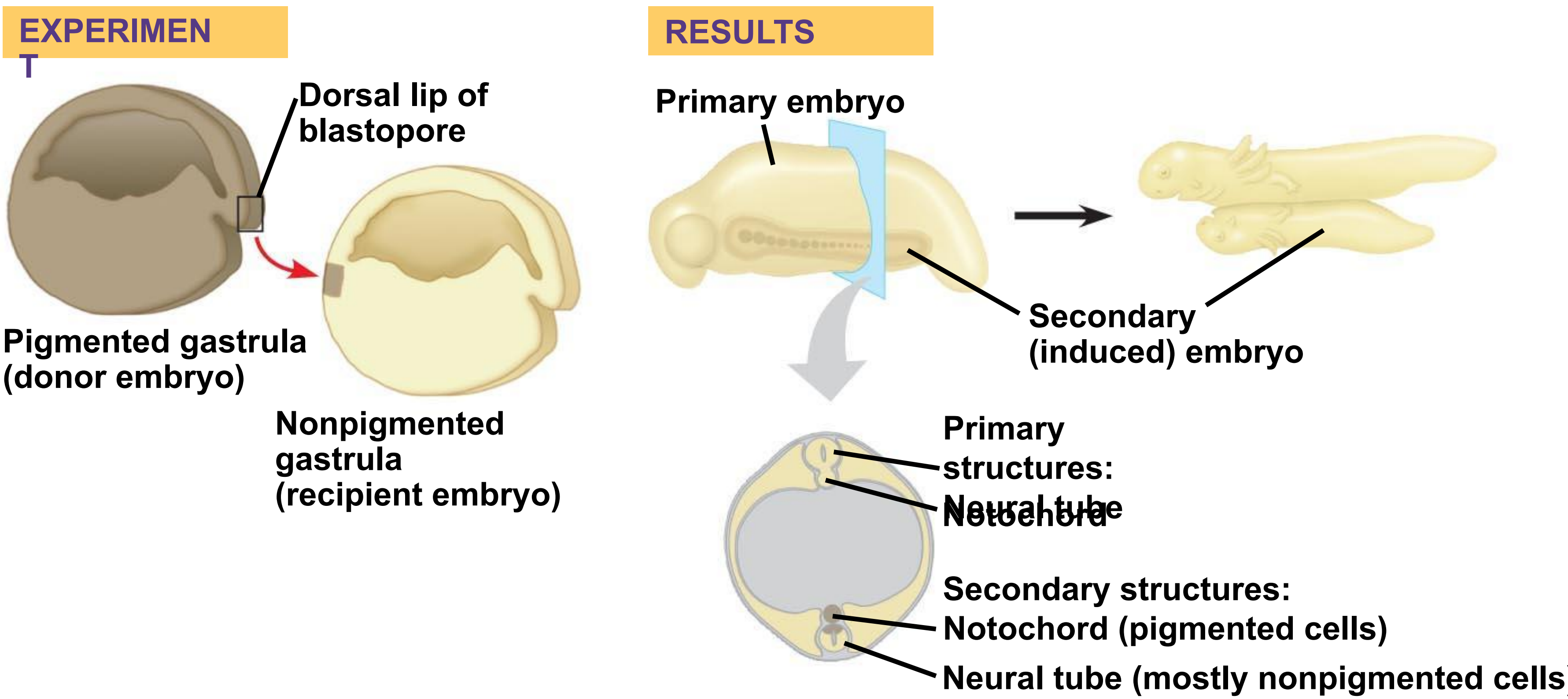
RESULTS



The Dorsal Lip = "Organizer" of Spemann and Mangold

- Based on their famous experiment, Hans Spemann and Hilde Mangold concluded that the ***blastopore's dorsal lip*** is an ***organizer*** of the ***embryo.***
- The Spemann organizer *initiates inductions* that result in *formation of the notochord, neural tube, and other organs*.

*Can the **dorsal lip** of the blastopore **induce cells** in another part of the amphibian embryo to **change their developmental fate?***

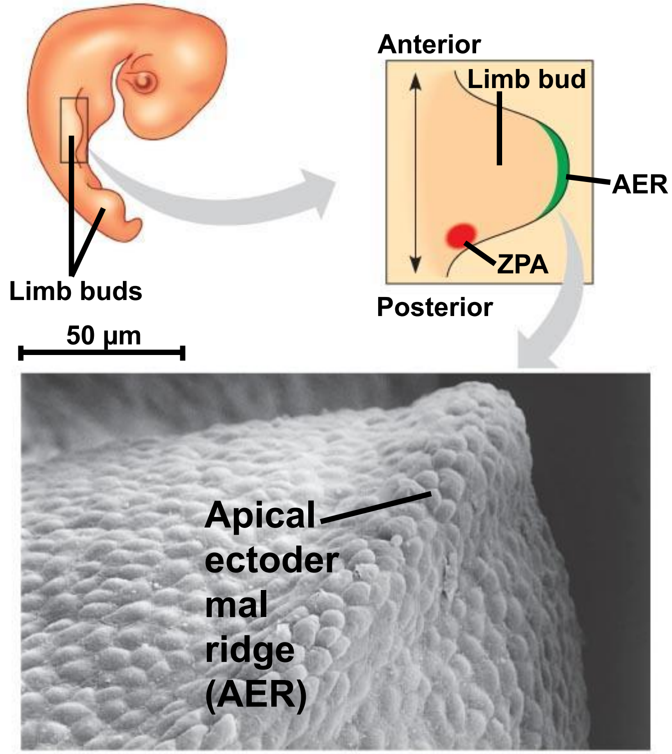


Formation of the Vertebrate Limb

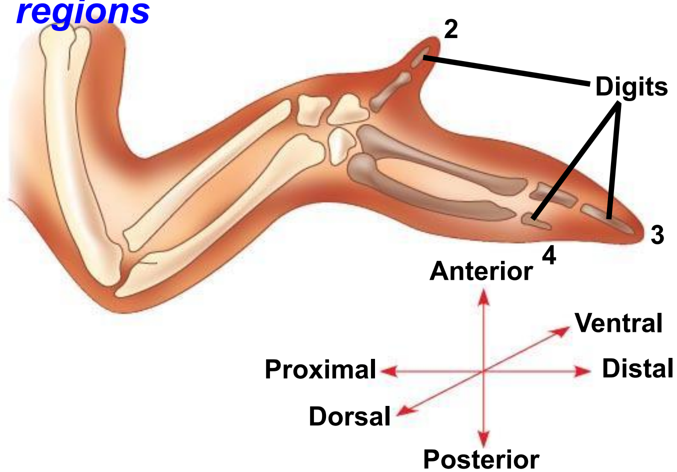
- Inductive signals play a major role in **pattern formation**, development of spatial organization.
- The molecular cues that control pattern formation are called **positional information.**
- This information tells a cell where it is with respect to the body axes.
- It determines how the cell and its descendents respond to future molecular signals.

- The wings and legs of chicks, like all vertebrate limbs, begin as bumps of tissue called limb buds.
- The embryonic cells in a limb bud respond to positional information indicating location along three axes
  - Proximal-distal axis
  - Anterior-posterior axis
  - Dorsal-ventral axis

Vertebrate limb development



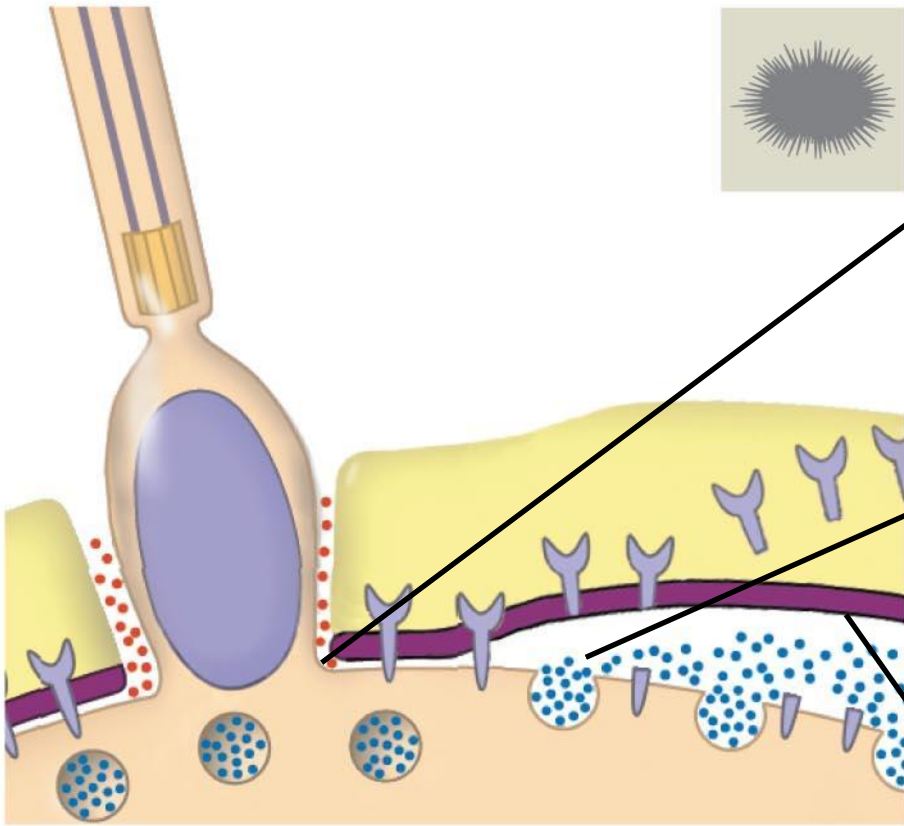
(a) Organizer regions



(b) Wing of chick embryo

- *Signal molecules* produced by inducing cells *influence gene expression* in cells receiving them.
- Signal molecules *lead to differentiation* and the development of particular structures.
- ***Hox genes*** also play roles during *limb pattern formation*.

Review



Sperm-egg fusion and depolarization of egg membrane (fast block to polyspermy)

↓

Cortical granule release (cortical reaction)

↓

Formation of fertilization envelope (slow block to polyspermy)

Review:
Cleavage frog embryo

2-cell stage forming

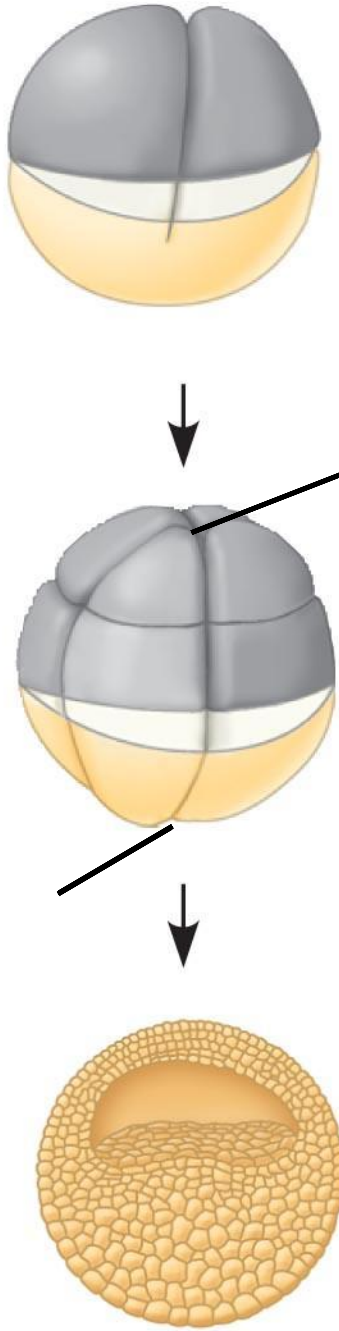
8-cell stage

Animal pole

Vegetal pole: yolk

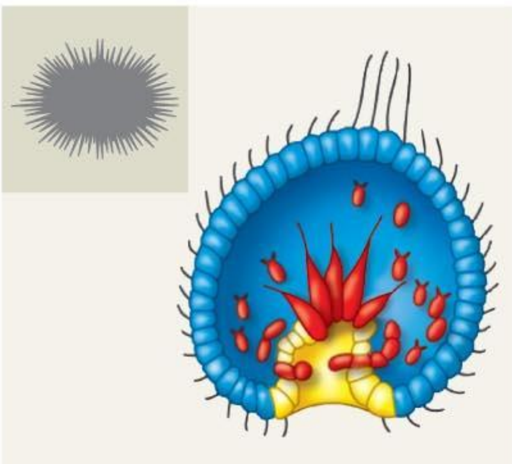
Blastula

Blastocoel

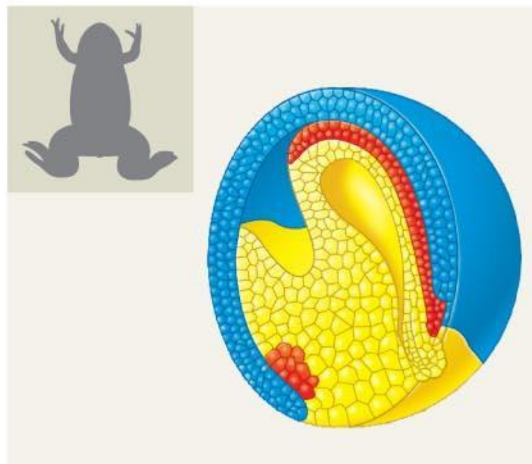


Review: Gastrulation / Early Embryonic Development

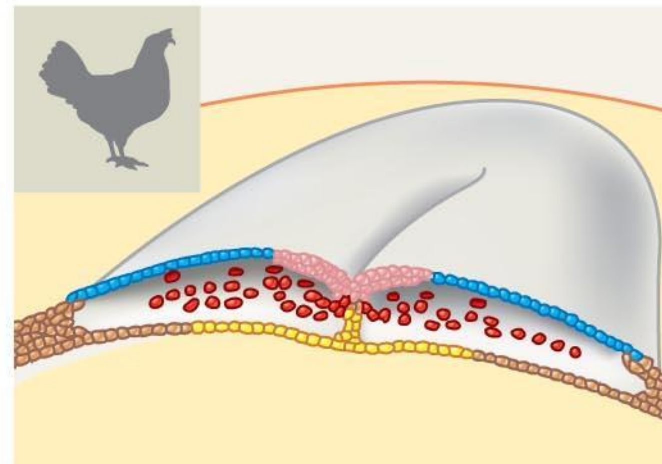
Sea urchin



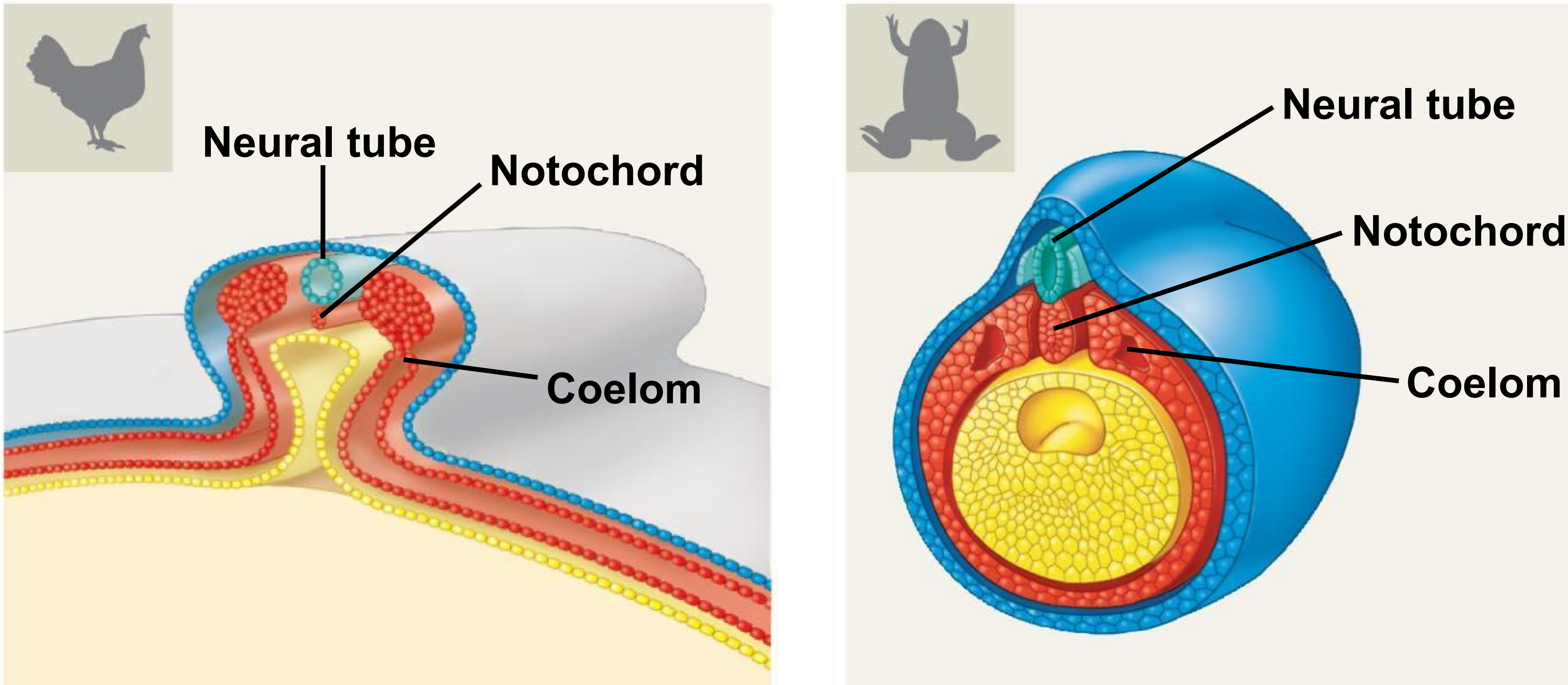
Frog



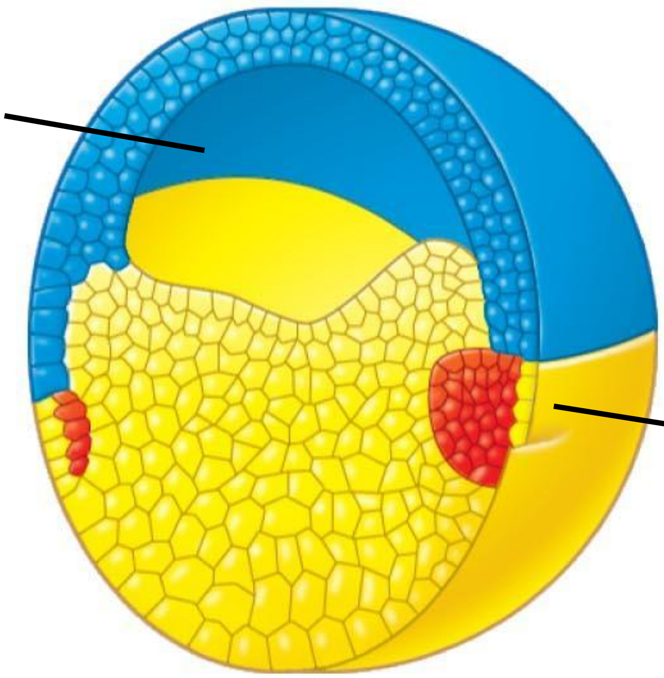
Chick/bird



Review: Early Organogenesis



Review: Fate Map of Frog Embryo



Species: ____________________

Stage: ____________________

You should now be able to:

1. Describe the acrosomal reaction.
2. Describe the cortical reaction.
3. Distinguish among meroblastic cleavage and holoblastic cleavage.
4. Compare the formation of a blastula and gastrulation in a sea urchin, a frog, and a chick.
5. List and explain the functions of the extraembryonic membranes.

6. Describe the role of the extracellular matrix in embryonic development.
7. Describe two general principles that integrate our knowledge of the genetic and cellular mechanisms underlying differentiation.
8. Explain the significance of Spemann's organizer in amphibian development.
9. Explain pattern formation in a developing chick limb.