Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce and to maintain dynamic homeostasis.

Enduring understanding 2.E: Many biological processes involved in growth, reproduction and dynamic homeostasis include temporal regulation and coordination.

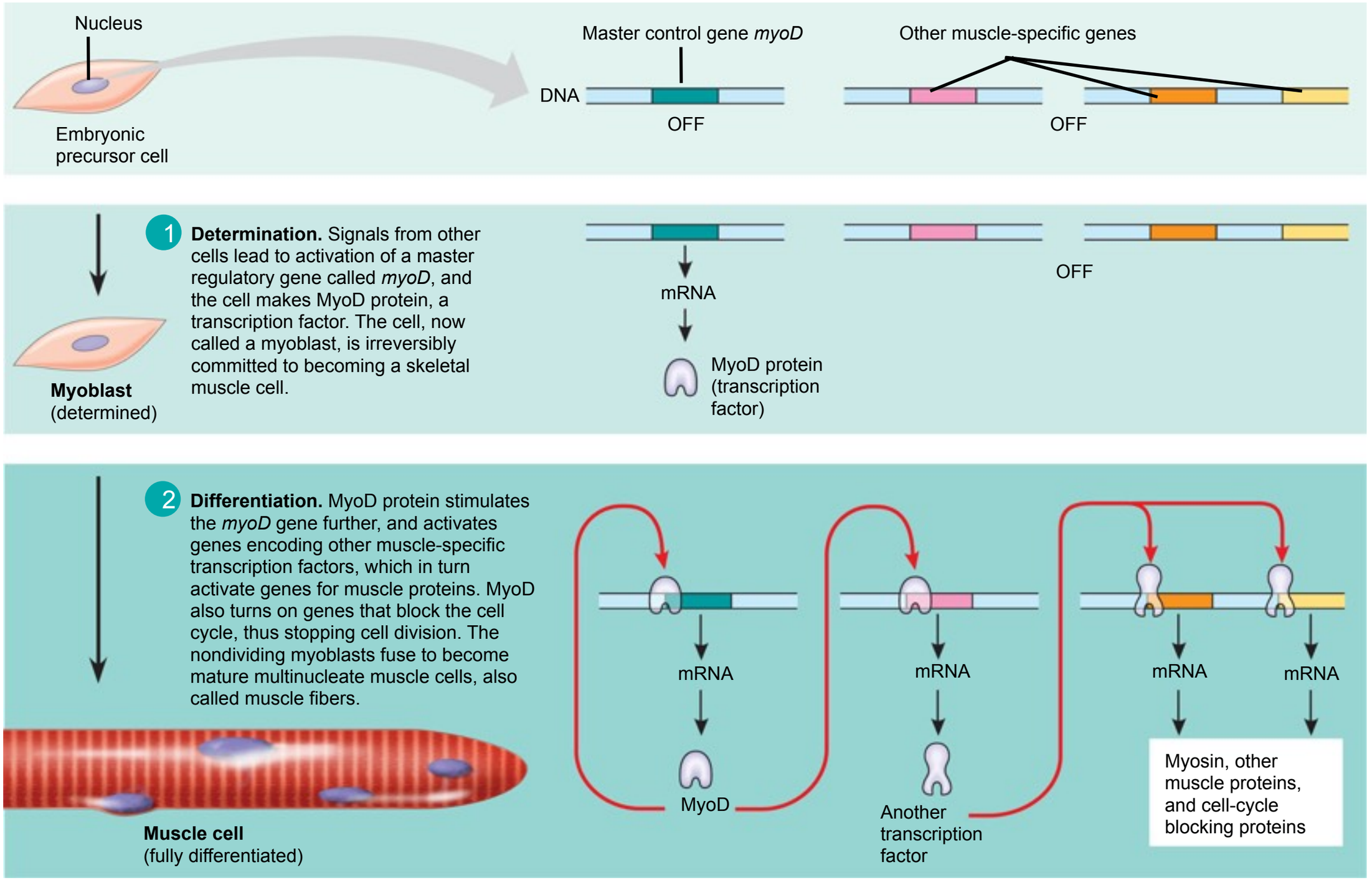
Essential knowledge 2.E.1: Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms.

a. Observable cell differentiation results from the expression of genes for tissue-specific proteins.

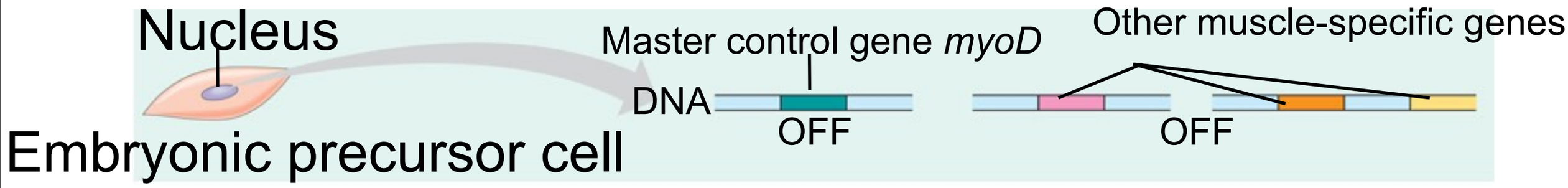
Transcriptional Regulation of Gene Expression During Development

- Cell determination
  - Precedes differentiation and involves the expression of genes for tissue-specific proteins
- Tissue-specific proteins
  - Enable differentiated cells to carry out their specific tasks

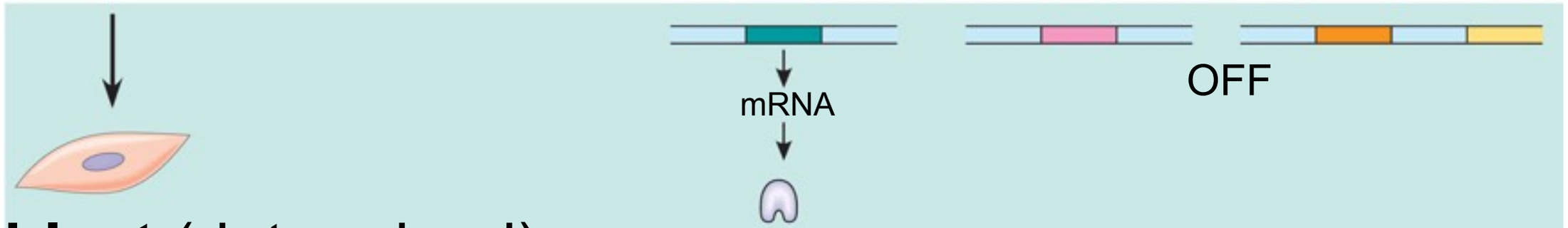
• Determination and differentiation of muscle cells



- Determination and differentiation of muscle cells



1 **Determination.** Signals from other cells lead to activation of a master regulatory gene called *myoD*, and the cell makes MyoD protein, a transcription factor. The cell, now called a myoblast, is irreversibly committed to becoming a skeletal muscle cell.

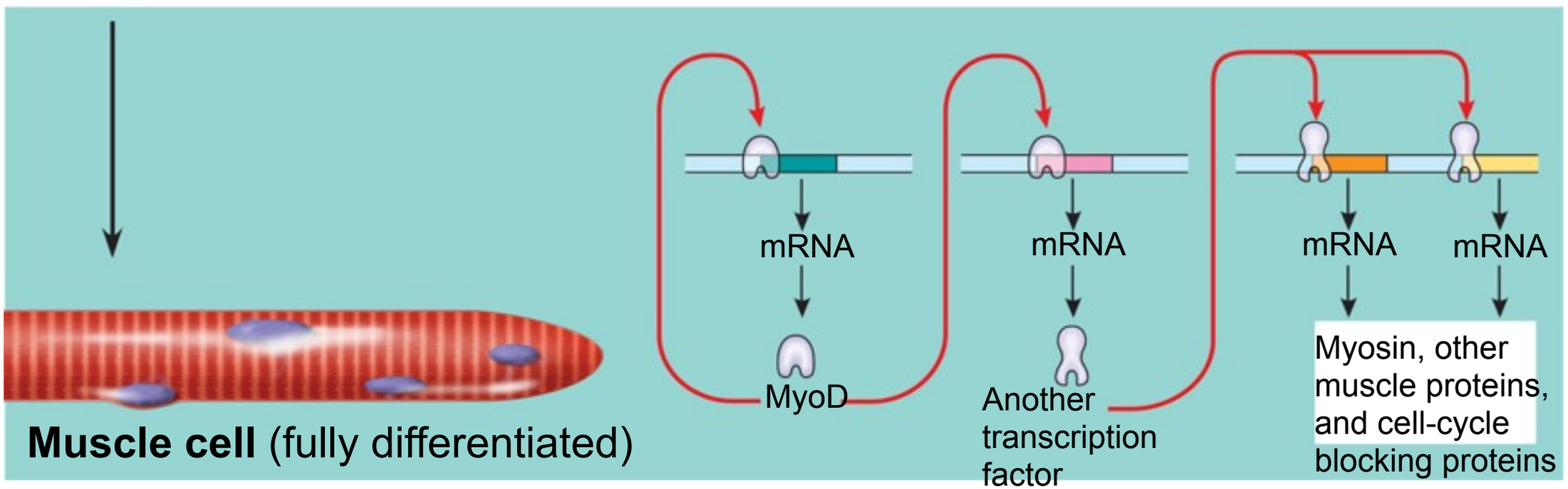


Myoblast (determined)

MyoD protein
(transcription factor)

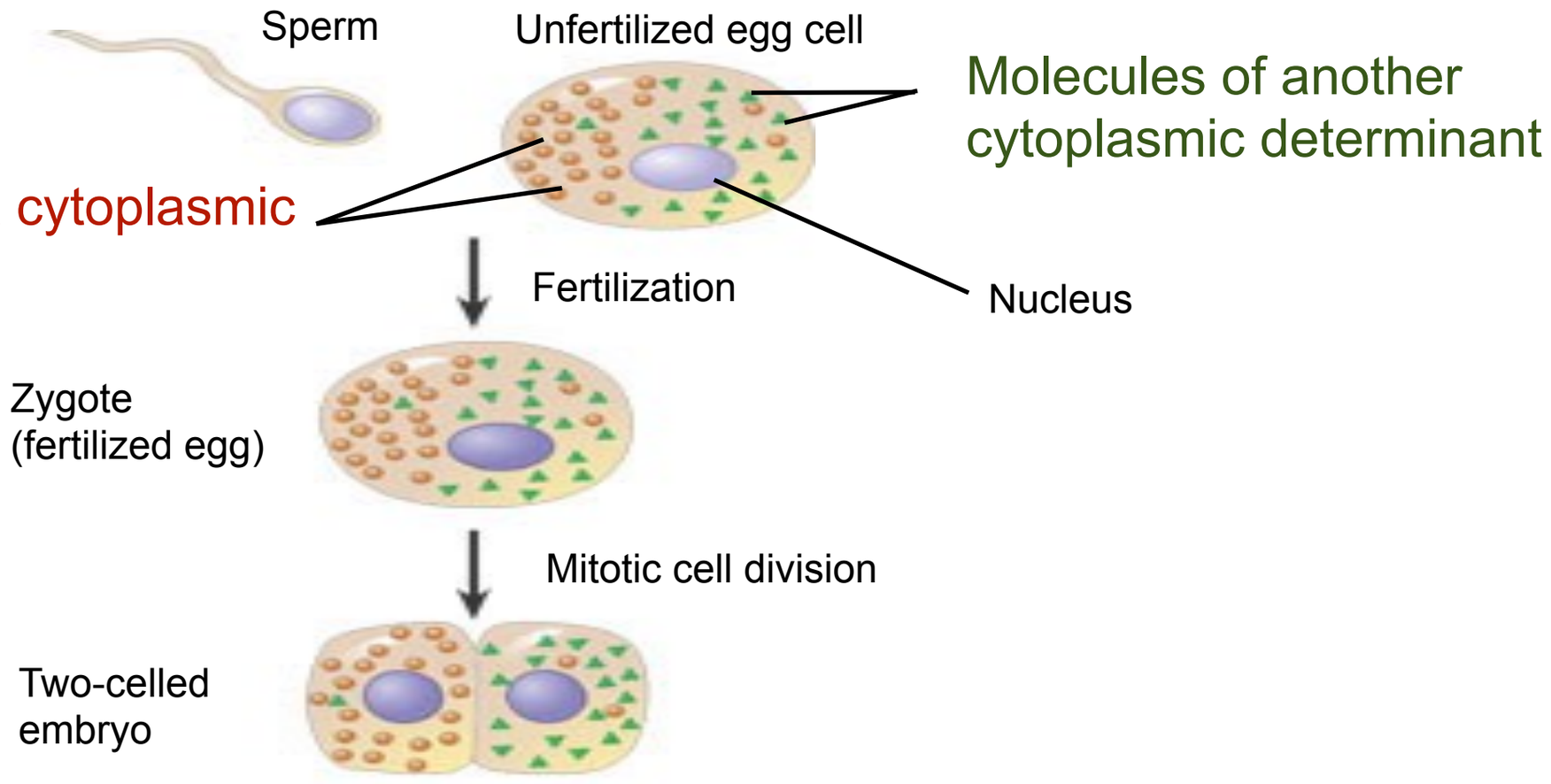
- Determination and differentiation of muscle cells

2 **Differentiation.** MyoD protein stimulates the *myoD* gene further, and activates genes encoding other muscle-specific transcription factors, which in turn activate genes for muscle proteins. MyoD also turns on genes that block the cell cycle, thus stopping cell division. The nondividing myoblasts fuse to become mature multinucleate muscle cells, also called muscle fibers.



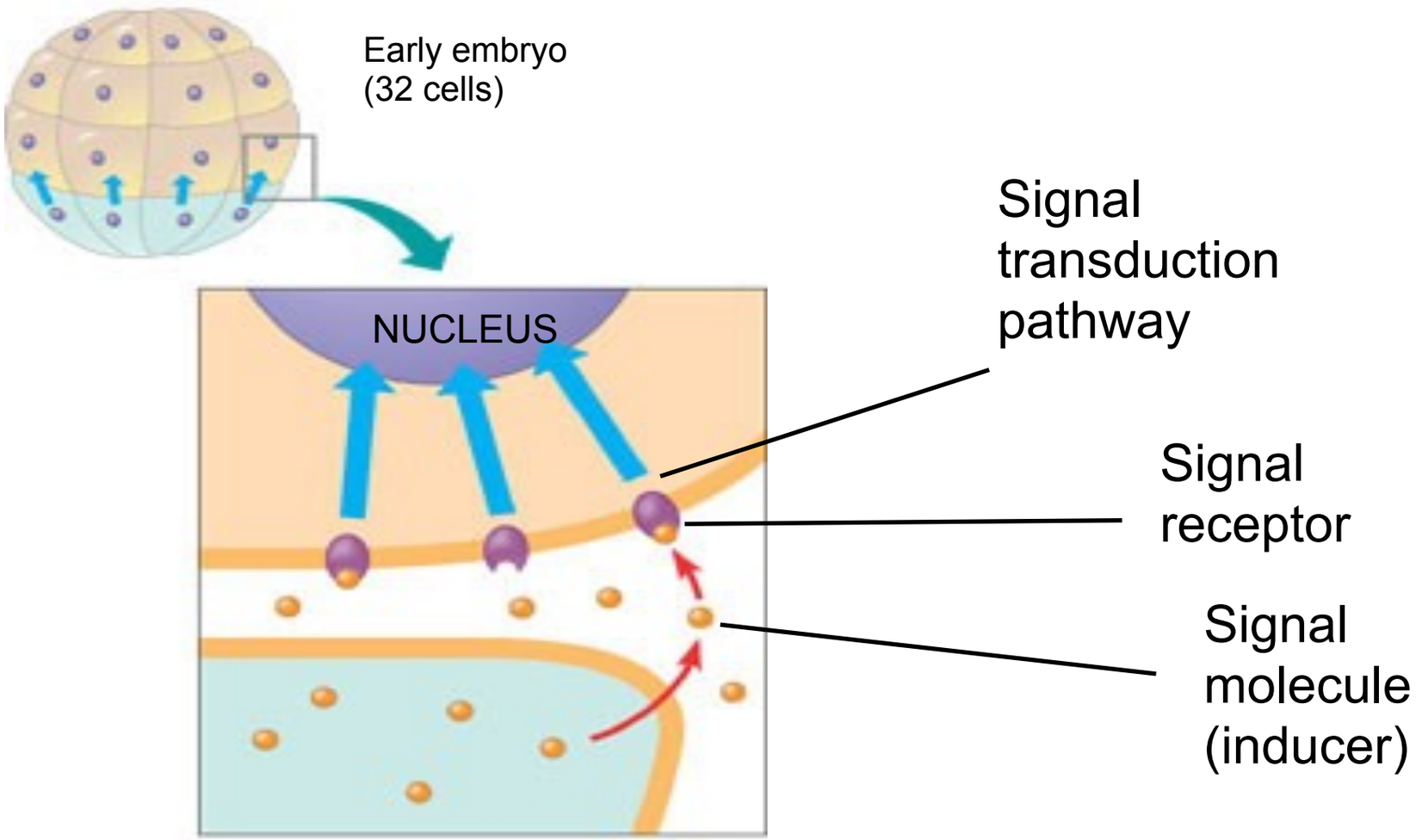
Cytoplasmic Determinants and Cell-Cell Signals in Cell Differentiation

- Regulate the expression of genes in the zygote that affect the developmental fate of embryonic cells



Cytoplasmic determinants in the egg. The unfertilized egg cell has molecules in its cytoplasm, encoded by the mother's genes, that influence development. Many of these cytoplasmic determinants, like the two shown here, are unevenly distributed in the egg. After fertilization and mitotic division, the cell nuclei of the embryo are exposed to different sets of cytoplasmic determinants and, as a result, express different genes.

- In the process called induction
  - Signal molecules from embryonic cells cause transcriptional changes in nearby target cells



Induction by nearby cells. The cells at the bottom of the early embryo depicted here are releasing chemicals that signal nearby cells to change their gene expression.

Essential knowledge 2.E.1: Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms.

b. Induction of transcription factors during development results in sequential gene expression.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Homeotic genes are involved in developmental patterns and sequences.
2. Embryonic induction in development results in the correct timing of events.
3. Temperature and the availability of water determine seed germination in most plants.
4. Genetic mutations can result in abnormal development.
5. Genetic transplantation experiments support the link between gene expression and normal development.
6. Genetic regulation by microRNAs plays an important role in the development of organisms and the control of cellular functions.

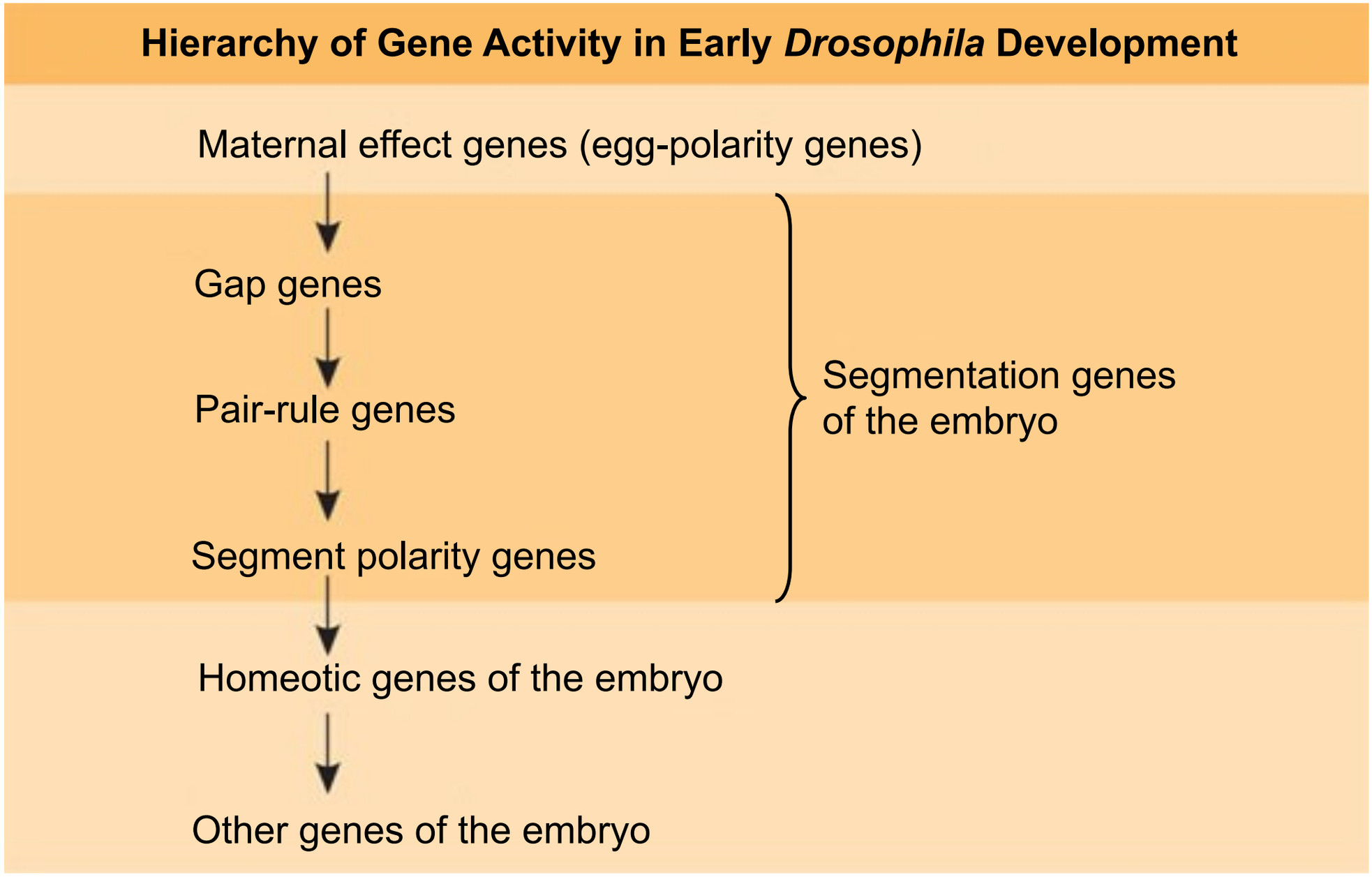
Segmentation Pattern

- Segmentation genes
  - Produce proteins that direct formation of segments after the embryo's major body axes are formed

Identity of Body Parts

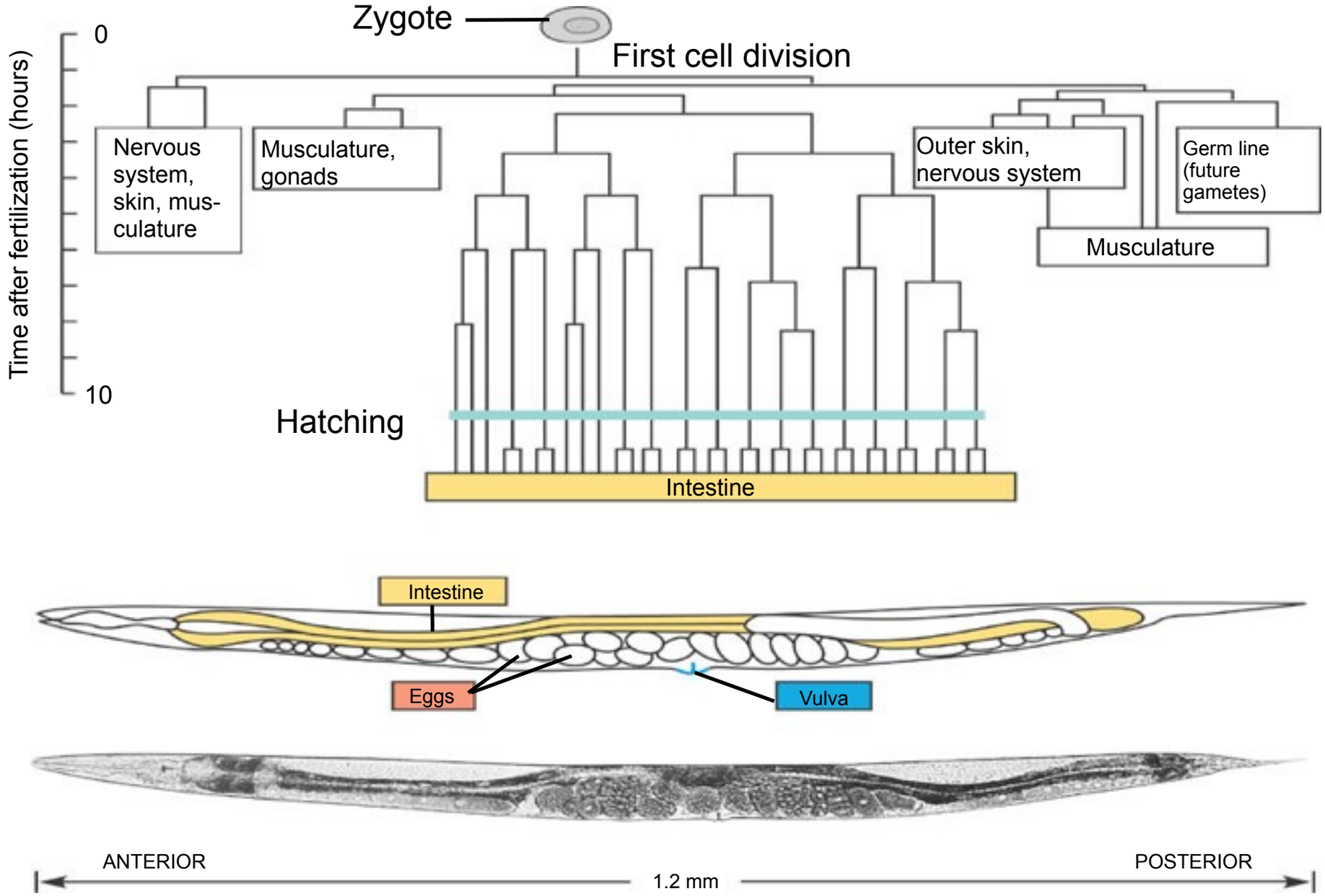
- The anatomical identity of *Drosophila* segments
  - Is set by master regulatory genes called homeotic genes

- A summary of gene activity during *Drosophila* development



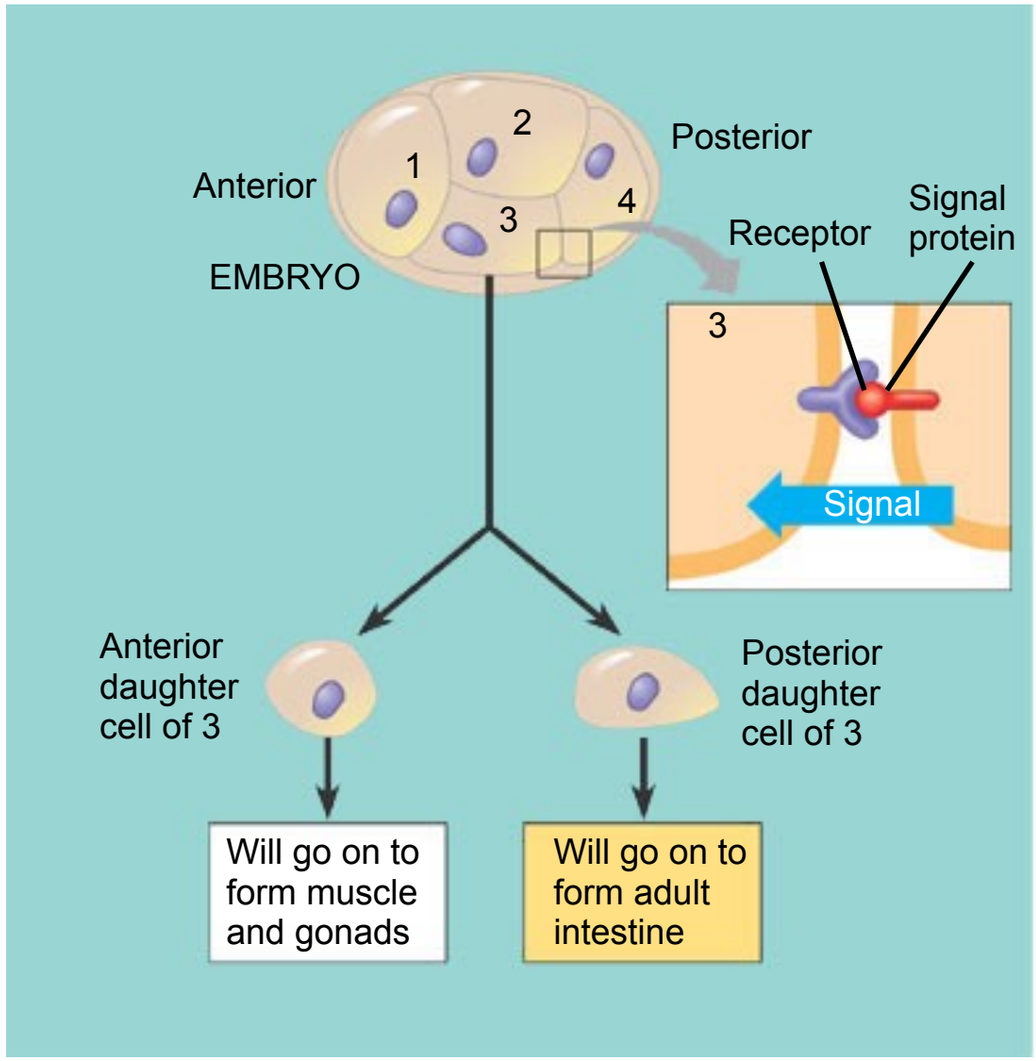
C. elegans: The Role of Cell Signaling

- The complete cell lineage
  - Of each cell in the nematode roundworm *C. elegans* is known



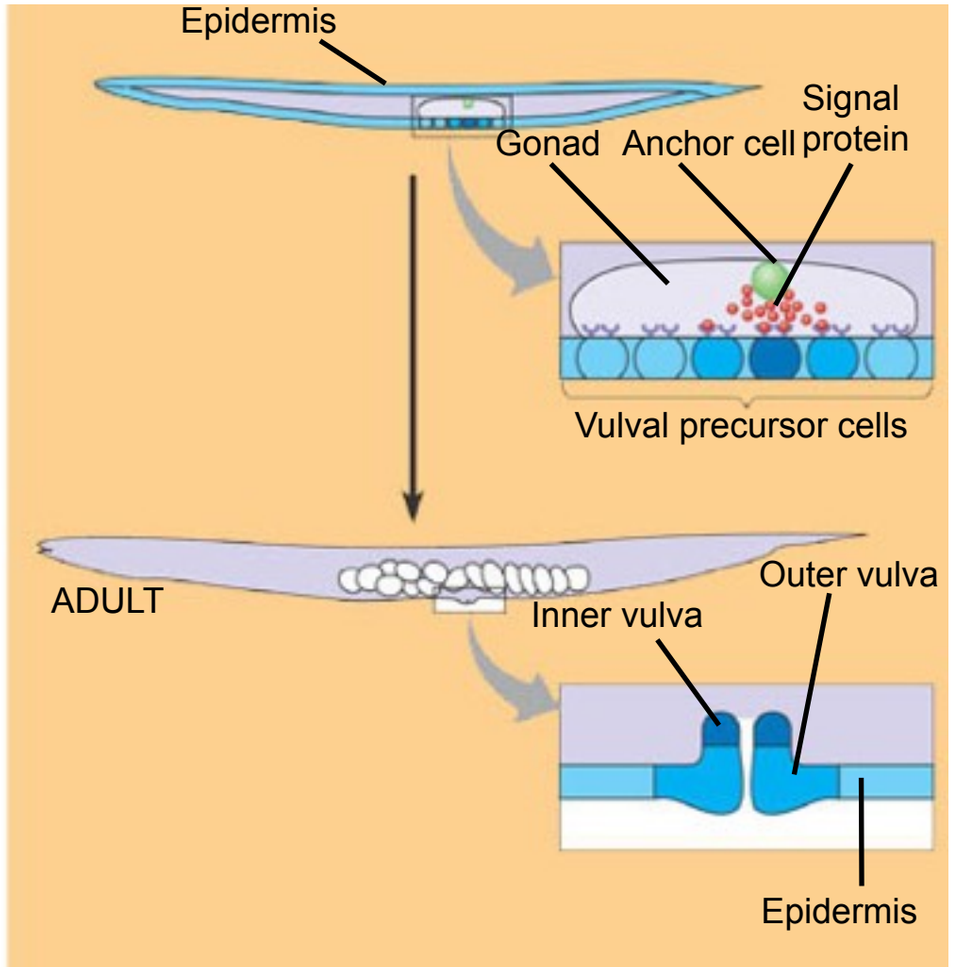
Induction

- As early as the four-cell stage in *C. elegans*
  - Cell signaling helps direct daughter cells down the appropriate pathways, a process called induction



(a)Induction of the intestinal precursor cell at the four-cell stage.

- Induction is also critical later in nematode development
  - As the embryo passes through three larval stages prior to becoming an adult



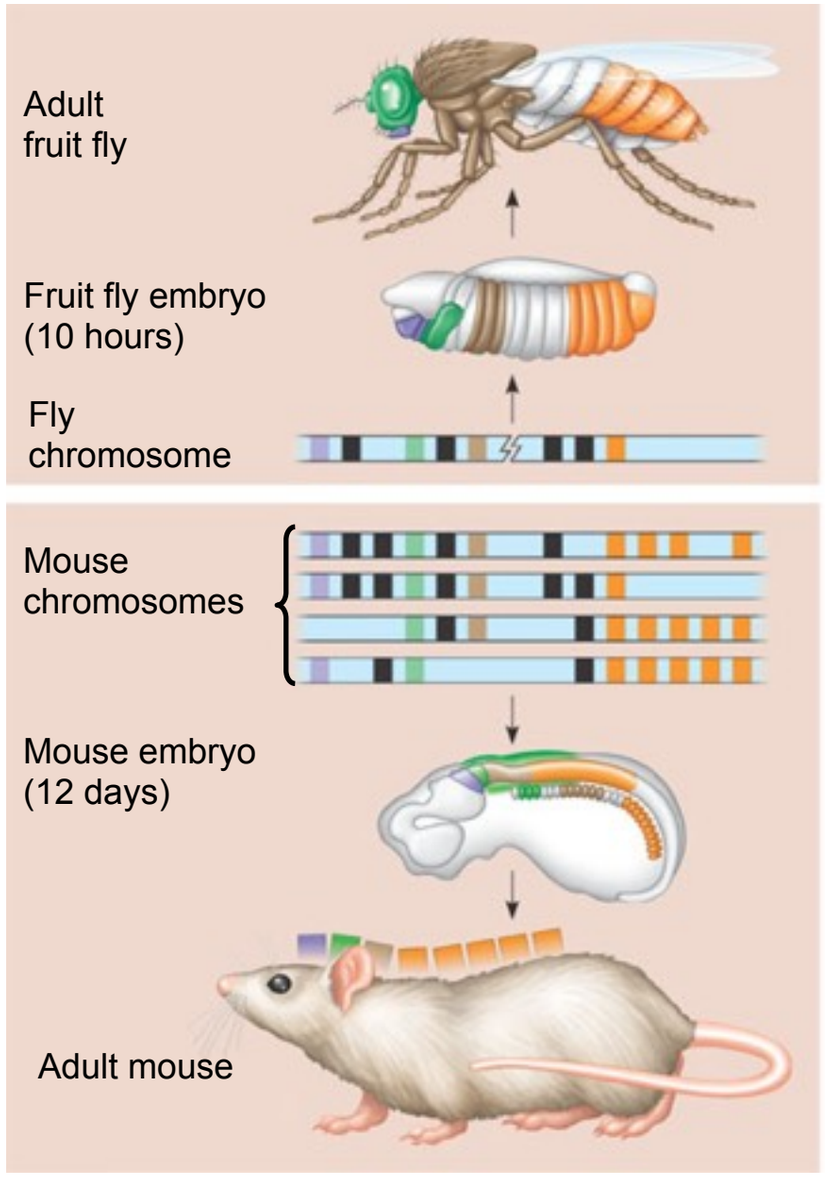
(b) Induction of vulval cell types during larval development.

- An inducing signal produced by one cell in the embryo
  - Can initiate a chain of inductions that results in the formation of a particular organ

Widespread Conservation of Developmental Genes Among Animals

- Molecular analysis of the homeotic genes in *Drosophila*
  - Has shown that they all include a sequence called a homeobox

- An identical or very similar nucleotide sequence
  - Has been discovered in the homeotic genes of both vertebrates and invertebrates



- Related genetic sequences
  - Have been found in regulatory genes of yeasts, plants, and even prokaryotes
- In addition to developmental genes
  - Many other genes involved in development are highly conserved from species to species

Comparison of Animal and Plant Development

- In both plants and animals
  - Development relies on a cascade of transcriptional regulators turning genes on or off in a finely tuned series
- But the genes that direct analogous developmental processes
  - Differ considerably in sequence in plants and animals, as a result of their remote ancestry

Essential knowledge 2.E.1: Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms.

c. Programmed cell death (apoptosis) plays a role in the normal development and differentiation.

Students should be able to demonstrate understanding of the above concept by using an illustrative example such as:

C. elegans development

Immune function

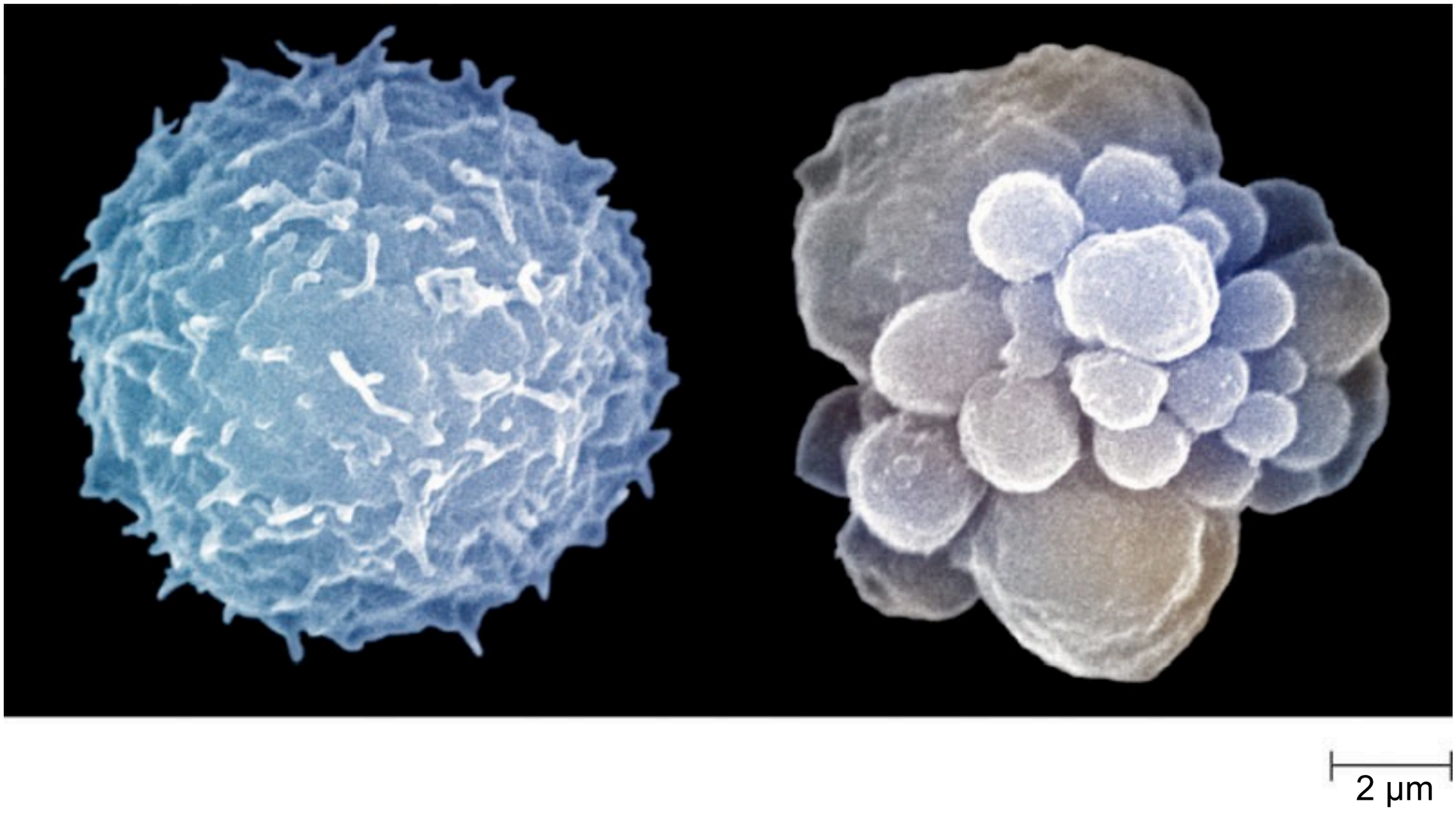
Flower development

Morphogenesis of fingers and toes

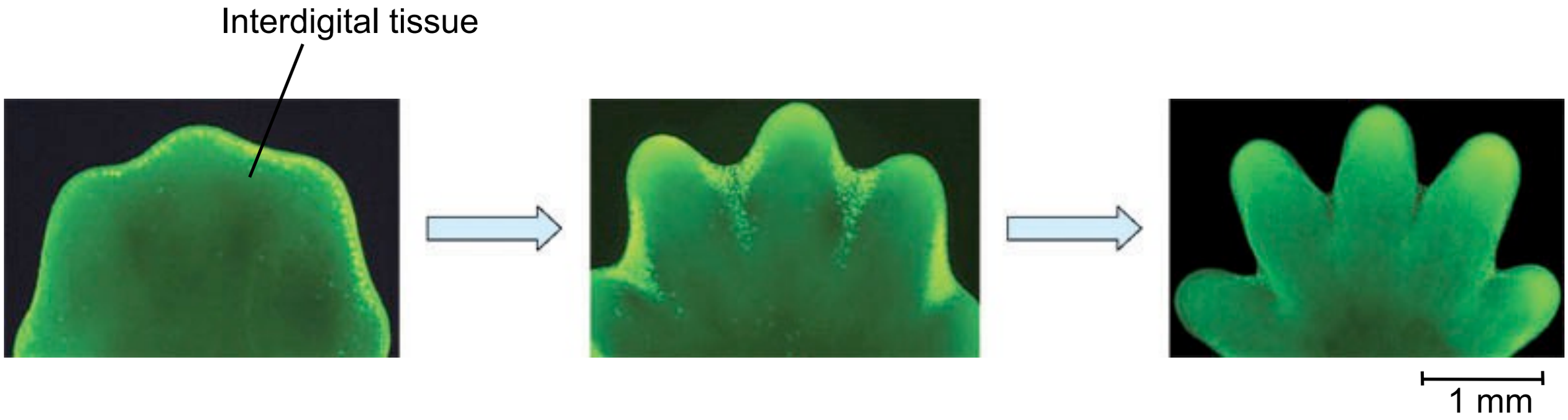
✘ Names of the specific stages of embryonic development are beyond the scope of the course and the AP Exam.

Programmed Cell Death (Apoptosis)

- In apoptosis
  - Cell signaling is involved in programmed cell death

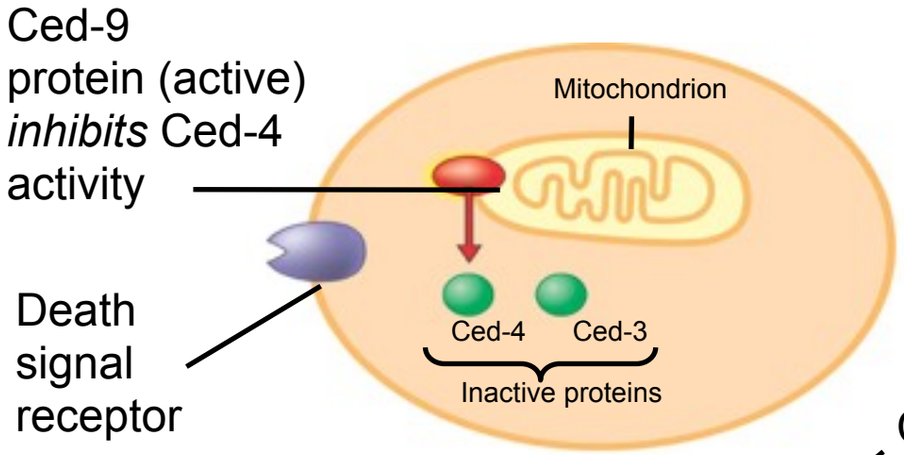


- In vertebrates
  - Apoptosis is essential for normal morphogenesis of hands and feet in humans and paws in other animals

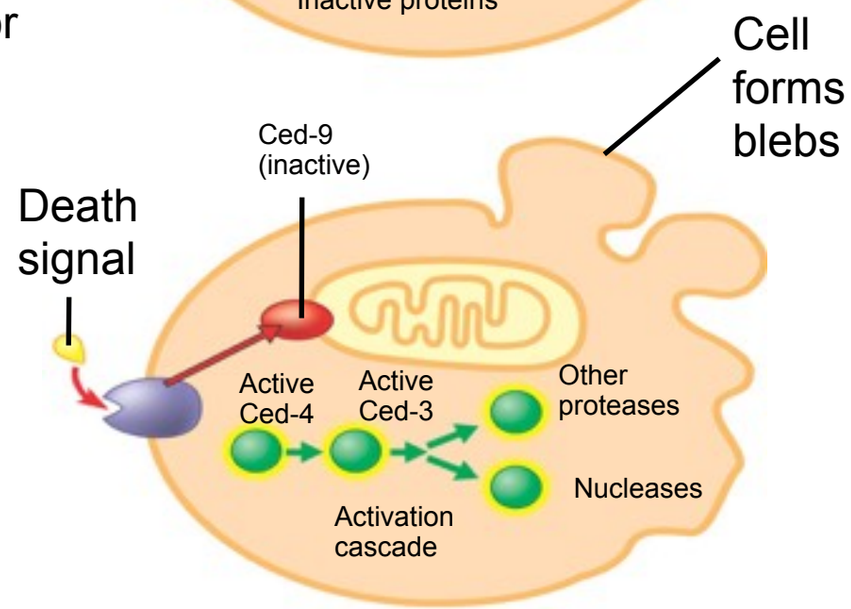


- In *C. elegans*, a protein in the outer mitochondrial membrane
  - Serves as a master regulator of apoptosis

(a) No death signal



(b) Death signal



Learning Objectives:

LO 2.31 The student can connect concepts in and across domains to show that timing and coordination of specific events are necessary for normal development in an organism and that these events are regulated by multiple mechanisms. [See SP 7.2]

LO 2.32 The student is able to use a graph or diagram to analyze situations or solve problems (quantitatively or qualitatively) that involve timing and coordination of events necessary for normal development in an organism. [See SP 1.4]

LO 2.33 The student is able to justify scientific claims with scientific evidence to show that timing and coordination of several events are necessary for normal development in an organism and that these events are regulated by multiple mechanisms. [See SP 6.1]

LO 2.34 The student is able to describe the role of programmed cell death in development and differentiation, the reuse of molecules, and the maintenance of dynamic homeostasis. [See SP 7.1]