Unit 2

**Multicellularity, Development, and Reproduction**

1. Describe the physiological challenges of and explain the adaptations for large cell size and multicellularity
   * Challenges:

* Plasma membrane: if a cell grows to large its cell will not have enough exchange capacity (surface area) to support the rate of exchange required for its increased metabolic activity (volume)
* Internal transport: the bigger the cell is, the more internal transport there will be as it takes longer to transport materials inside them because there is more distance to cover
  + Adaptations:
* Cell geometry: some cells have features that increase surface area relative to volume like the cell being long and thin or having many protrusions
* Reproduction: a cell will divide into two when it becomes too large to live as one
* Internal complexity: eukaryotic cells have organelles that compartmentalize and perform specific tasks, they also contain the cytoskeleton (that transports material at a faster rate than diffusion)
* Multicellularity: organism is made up of multiple cells with specialized functions

1. Explain the roles of the five essential developmental processes in development of a multicellular organism
   * Multicellularity: being composed of multiple cells
   * Specialization: different cells carry out different functions
   * The evolution of multicellularity and specialization resulted in the requirement for development
   * Development processes:

* Cell proliferation: reproduction of new cells via mitosis
* Programmed cell death: cells that die during specific times of development
* Cell movement/differential expansion: cells can move to new locations in the body (ex. Gastrulation or the process of forming the gut). For plants cells can’t move so they instead differentially expand causing the plant to bend.
* Induction: cell-cell communication or signaling, important for cells to recognize where they are in the body during development + what type of cell they’ll become. Can occur between adjacent cells or across a long distance. Morphogen, any signaling molecule that helps specify cell fate that is present in a concentration gradient. Amount of morphogen a cell detects helps determine what the cell will become.
* Cell differentiation: process of becoming a specific cell type, often a final result of all the other processes, the cell goes from an unspecified (embryonic) type to a final specialized type of cell with a specific job

1. Describe the major reproductive strategies of eukaryotes
   * Asexual reproduction: the offspring is an exact genetic copy of the parent

* Advantages: relative speed and low energy cost compared to finding and courting (attracting) a mate
* Mitosis: splitting into two (usually equal) halves
* Multiple fission: splitting into more than 2 cells
* Budding: outgrowth of a new cell from an old cell/new organism from old organism, can occur when a single cell buds from a parent cell or when multiple cells bud off a larger organism
* Fragmentation: mature organism splits into fragments capable of forming new organisms
* Spores: specialized cells capable of forming a new organism
* Parthenogenesis: development of unfertilized egg into new organism
* Polyembryony: fertilized egg splits to form genetically identical clones
* Vegetative growth: growth of new organism from meristematic cells without spores or gametes
  + Sexual reproduction: combination of usually haploid reproductive cells from two individuals to form a new usually diploid unique offspring
* Requires the time and energy to find a mater and only half of the populations can actually make offspring
* When everything is equal asexual reproduction will out compete sexual reproduction

1. Explain the trade-offs between asexual and sexual reproduction, and predict which replication mode is more likely in different environmental conditions
   * Daphnia pulex: can switch between sexual and asexual reproduction
   * Sexual reproduction is more common in crowded populations then sparse
2. Compare and contrast the three types of life cycles of eukaryotes
   * Gametogenesis: making gametes, which are typically called eggs and sperm
   * Mating: getting gametes together, which involves sperm and egg being released at the same time and location
   * Fertilization: Fusing gametes into a single cell which is then called a zygote
   * Life cycles: different organisms accomplish these three steps in different ways and at different times in their life cycles. All life cycles involve a haploid (1 complete set of chromosomes) and diploid (2 complete sets of chromosomes) stage but vary in how and when in the life cycle these stages occur
   * Diplontic: typical of animals, multicellular organism is diploid (2n)
   * Haplontic: typical of algae, fungi, the mature organism is haploid (n)
   * Alternation of generations: typical of plants, there are two mature multicellular organisms (one haploid and one diploid)
   * Gametes: a mature haploid male or female germ cell that is able to unite with another of the opposite sex in sexual reproduction to form a zygote
   * Spore: a small, typically one-celled, reproductive unit capable of giving rise to a new individual without sexual fusion

**Animal Reproductive Strategies**

1. Differentiate between internal and external fertilization and identify environmental and organismal traits associated with each type of fertilization
   * Fertilization: combination of a sperm and an egg
   * Internal fertilization: happens inside body of the female

* Happens in most terrestrial animals but can happen in aquatic mammals and fish
* Three ways:
* fertilized eggs are laid outside the female’s body and the embryo develops in there nourished by the yolk in the egg (birds, many reptiles, most amphibians, 2 mammals)
* Fertilized egg stay in the females body and embryo is nourished by the yolk, they hatch when they’re fully developed and then exit to the environment (bony fish, lizards, snakes, vipers, some invertebrate animals)
* Fertilized eggs stay in the females body and are nourished by the placenta and may or may not be fully developed before exiting the females body (most mammals, few reptiles)
* Advantages: protecting egg from dehydration, embryo remains within female, increases likelihood of fertilization by a specific male, fewer offspring’s produced through this way but their rate of survival is higher than external
  + External fertilization: happens outside body of the female
* happens in aquatic environments and done by fully aquatic organisms like fish or partly aquatic organisms like amphibians
* water keeps the eggs from drying out
* the two gametes (eggs and sperm) need to release at the same time and in the same location
* Some species release all at the same time after being triggered by a specific environment element (temperature, length of daylight) and other fertilize individually by the male courting a female to induce her to release her eggs

1. Explain why females are more likely than males to be “choosy” when selecting a mating partner
   * Females invest more into the offspring and has a limited number of eggs compared to the amount of sperm a male has
   * If a female mates with a genetically inferior male, her offspring may not survive and this would mean she invested time and energy for nothing
   * Eggs are expensive and sperm are cheap
   * A female will maximize reproductive success by mating with the best male
2. Define adaptation, biological fitness, sexual selection, and sexual dimorphism, and recognize that sexual selection can operate on any sexually reproducing population
   * Sexual selection: where one sex prefers certain characteristics in individuals of the other sex, leading to increased reproductive success of individuals who have that particular characteristic
   * Adaptations: anything that increases an individual’s reproductive success
   * Biological fitness: reproductive success relative to others in the population
   * Sexual dimorphism: distinct differences in size or appearance between males and females as a result of the competition between males due to the choosiness of females
   * A diagram of a diagram

     Description automatically generatedSecondary sexual characteristics: exaggerated or showy physical traits that are associated with mating behaviors and reproductive success
3. Differentiate between direct male competition, indirect male competition, and female choice, and identify examples and advantages of each
   * Direct male competition: occurs when females mate only with a single male, typically the winner

* Male-male aggression: male fight with each other for access to females

Ex. Lions fighting over a pride of female lions

* Courtship rituals: males engage in “dances” or other displays to attract females

Ex. Male bower bird building an elaborate nest

* Lekking: a specialized form of courtship where many males gather together in one place and “display” at the same time, allowing females to choose among them

Ex. Peacocks gathering to display to females

* + Female choice (intersexual selection): females choosing which males to mate with based on observing the male competition
* This leads to the selection of showy traits that increases the males biological fitness but not survival
* This is supported by the good genes hypothesis which says that these showy male traits are “honest indicators” of good genetic quality (takes good genetics to make a big flashy tail and avoid being eaten by predators)
  + Indirect male competition: males can compete for fertilization of a females eggs after mating has already occurred, likely to occur in species where the female is likely to mate with multiple males
* Instead of males directly competing with each other, they are competing via their sperm
* In other words, if a female mates with more than one male, then any male whose sperm end up fertilizing more eggs is going to have more offspring, on average, than other males..  So if there is a trait that makes this male’s sperm more successful than other male’s sperm, then that trait is going to end up increasing in the population over generations.
* First male advantage:
  + mate guarding: a male remains close by the female after mating, preventing other males from mating with her until there has been time for his sperm to fertilize her eggs
  + copulatory plugs: males ejaculate includes a sticky residue which temporarily blocks entry to the females reproductive tract making it more difficult for other males to mate with her until theres been time for his sperm to fertilize her eggs
* Second male advantage:
* Elaborate penis morphology: elaborate structures on the penis help remove the sperm of previous males from the females reproductive tract by scraping out previous ejaculate
* Large ejaculate volume and large testes: a large volume of ejaculate helps to flush out the sperm deposited in the female’s reproductive tract by the previous male; a large ejaculate volume means the testes must also be large, in order to have enough space to hold all the sperm
* Cryptic female choice: female is capable of preferentially using sperm from a specific male even if she has mated with multiple males

1. Define and recognize examples of parental investment
   * Parental investment: Parental investment is any energy, effort, or resource that a parent provides to increase the offspring’s chances of survival, but at the cost of the parent’s ability to invest in other offspring

Ex. A male songbird collecting food for one nest of hatchlings, at the expense of others, male toad carrying fertilized eggs on hind legs until they are ready to hatch

1. Differentiate between animal mating systems and predict relationships between these mating systems and sexual dimorphism or sperm competition

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A diagram of a cycle

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**Animal Reproductive Structures and Functions**

1. Identify and describe functions of key anatomical reproductive structures present in various types of animals, including the spermatheca, the cloaca, the ovary and related structures, and the testes and related structures
   * Males produce sperm in testes that are stored in the epididymis until ejaculation (sperm are small, mobile, and low cost)
   * Females produce one ovum or several ova (eggs) that mature in the ovary (large, require investment of time, energy, and nutrients to form, and are non-mobile)

* Mature eggs are released from the ovary into the uterine tubes (fallopian tubes/oviducts)
  + Spermatheca: specialized sperm-storing sac present in females in some invertebrate species, used for storing the male’s sperm for later use, up to a year after. Fertilization can be put off until environmental or food conditions are optimal for offspring survival.
  + Cloaca: single, shared body opening that functions in the digestive, excretory (urine), and reproductive systems (found among many non-mammals like birds and reptiles)
  + Uterus: structure in placental mammals, housing the developing offspring internal to the mother’s body can have multiple chambers or one chamber
  + Gametogenesis: production of gametes (sperm and eggs) which requires meiosis, producing haploid cells with half the number of chromosomes normally found in diploid cells
  + Human female reproductive anatomy:
* A screenshot of a computer

  Description automatically generatedInternal structures: ovaries, oviducts, the uterus, and the vagina
* Human females become capable of reproduction after puberty, during puberty the hypothalamus signals the pituitary gland to produce **follicle-stimulating hormone(FSH)** and **luteinizing hormone(LH)**
* FSH and LH stimulate the ovaries to produce the female sex hormone **estrogen and progesterone** which initiates the development of secondary sex characteristics
* Ovaries: site of egg development and maturation
* Follicles: where eggs develop and mature, found throughout the ovary
  + Each follicle contains one immature egg
* Ovarian cycle: monthly cycle in which one or two eggs mature
* Oviducts: where the egg that ruptured from the follicle will travel and where it will be fertilized by a sperm if present
  + Will travel from oviduct to uterus where it will implant and result in pregnancy if fertilization happened
* Corpus luteum: what the ruptured follicle becomes which secretes hormones that prevents menstruation until the egg has had time to be fertilized, if fertilization doesn’t happen it will degenerate and menstruation occurs
  + Male reproductive anatomy:
* A table with text on it

  Description automatically generatedInternal structure: vas deferens, the seminal vesicles, the prostate gland, and the bulbourethral gland
* Become capable of reproduction at sexual maturity after puberty
* During puberty, the hypothalamus in the brain signals the pituitary gland to produce two hormones, **follicle-stimulating hormone** (**FSH**) and **luteinizing hormone** (**LH**). In males, FSH and LH stimulate the testes to produce sperm and the male sex hormone, **testosterone.**During puberty, these hormones together initiate development of secondary sex characteristics (such as larger penis and testes, and deeper voice) and cause the testes to begin producing mature sperm.
* Scrotum: houses the testes (testicles), site of sperm development and maturation
  + Testes have to be outside the body in order for the sperm to stay at the ideal temperature, at too high a temperature they become immobile
  + Warmed to body temperature when about to be deposited in the female, in order to promote motility and swimming activity, but then loss motility after several hours at body temperature
* Seminiferous tubules: where sperm is produced
  + Sertoli cells: protects the sperm stem cells and promotes their development
  + Cells of Leydig: produce testosterone and regulate sperm development
  + Sperm mature as they proceed from the periphery to the lumen (interior) of the seminiferous tubules
* Epididymis: where the sperm go after developing flagella and leaving the testes
* Vas deferens: where the sperm goes during ejaculation which carried the sperm and forms the ejaculatory duct with the duct from the seminal vesicles
* Semen is a mixture of sperm and spermatic duct secretions and fluid from accessory glands
  + Glands are: seminal vesicles, prostate gland, and the bulbourethral gland (make up most of the semen)
  + Seminal vesicles: a pair of glands that make thick, yellowish, and alkaline solution. As sperm are only motile in an alkaline environment, a basic pH is important to reverse the acidity of the vaginal environment. The solution also contains mucus, fructose (a source of energy for the sperm cells), a coagulating enzyme, ascorbic acid (vitamin C), and local-acting hormones called prostaglandins (may help stimulate smooth muscle contractions in the uterus). The seminal vesicle glands account for 60 percent of the bulk of semen.
  + Prostate gland: acts as both a muscle and a gland. The muscle provides much of the force for ejaculation to occur. The glandular tissue makes a thin, milky fluid that contains citrate (stimulates sperm motility), enzymes, and prostate specific antigen (PSA). PSA is a proteolytic enzyme that helps to liquefy the ejaculate several minutes after release from the male. Prostate gland secretions account for about 30 percent of the bulk of semen.
  + Bulbourethral gland: releases its secretion just *before* release of the bulk of the semen. The mucous secretions of this gland help lubricate and neutralize any acid residue in the urethra left over from urine. Secretions from the bulbourethral gland can also contain a few sperm; since these secretions are released prior to ejaculation, withdrawal of the penis from the vagina before ejaculation to prevent pregnancy may not work if sperm are present in the bulbourethral gland secretions.

1. Compare and contrast the process, products, and locations of male and female gametogenesis in mammals **AND** Describe roles of hormones in gametogenesis (spermatogenesis and oogenesis), ovulation, and implantation in placental mammals
   * Female gametogenesis (Oogenesis): directly controlled by four hormones (FSH, LH, progesterone, estrogen)

* Hormones regulate the ovarian (release of eggs) and menstrual cycles (activities in the uterine lining in preparation for possible pregnancy)
* Hormones and what they do:
* Follicle stimulating hormone (FSH) activates follicles within the ovary to promote development of egg cells, causing eggs to finish meiosis I and pause during meiosis II. (Recall that each follicle contains one immature egg cell which was paused in meiosis I.)
* Luteinizing Hormone (LH) promotes release of the most mature egg (or in rare cases, eggs), resulting in ovulation
* Progesterone suppresses release of more FSH or LH to block activation of new follicles, allowing time for the ovulated egg to be fertilized in the oviduct and then travel to the uterus where it will implant if previously fertilized.
* Estrogen can be thought of as an ‘enhancer’ in the ovarian cycle; it enhances the activation of follicles in response to FSH, and it also enhances suppression of follicles in response to progesterone. (Estrogen also has other roles outside of the ovarian cycle, including re-growing the lining of the uterus following menstruation, and it is responsible for the secondary sexual characteristics of females such as breast development.)
* Phases in ovarian cycle:
* Follicular phase: dominant feature is the activated follicles, FSH released from the pituitary prompts the follicles to grow and begin maturing an egg. The growing follicle releases estrogen, enhancing the effects of FSH. More estrogen from the follicle, causes more growth of the follicle (positive feedback loop). The paused meiosis I of the egg resumes and then pauses on meiosis II.
* Ovulation: near the middle of the cycle (day 14), the high level of estrogen (from developing follicles) causes a rapid rise and sharp spike in levels of LH and less of FSH. The LH spike causes ovulation, the mature follicle ruptures and releases an egg that is still paused on meiosis II. After ovulation, FSH and LH levels fall immensely, and estrogen also decreases after extra follicle degenerates. The egg will complete meiosis II if fertilized, producing a single mature egg.
* Luteal phase: dominant feature is corpus luteum. Corpus produces progesterone and estrogen, progesterone inhibiting the release of further FSH and LH, suppressing activation of more follicles. Estrogen enhances effects of progesterone, and the levels of estrogen produced by the corpus luteum increases to a steady level for the next few days.
  + If the egg was fertilized in the oviduct it either doesn’t implants in the endometrial lining of the uterine wall and the corpus luteum degenerates (decreasing the levels of estrogen and progesterone), causing the FSH to start being released by the pituitary
  + A diagram of the uterus

    Description automatically generatedDiagram of a uterus and ovulation

    Description automatically generatedA diagram of menstrual cycle

    Description automatically generatedA diagram of a cell phone

    Description automatically generatedOr it does implant in the endometrial lining of the uterine wall, producing hCG, which causes the corpus to remain, and causes high levels of progesterone, preventing initiation of another ovarian cycle during the pregnancy
  + Male gametogenesis: spermatogenesis: occurring in the seminiferous tubules in the testes. Spermatogonia are present at birth but inactive until puberty. For sperm, a spermatocyte cell undergoes meiosis to produce four haploid spermatids (immature sperm), and once it develops a flagellum it is considered a sperm cell. 4 sperm cells result from each spermatocyte that goes through meiosis.
* Hormonal control of spermatogenesis:
* FSH stimulates activity of the Sertoli cells to nourish the developing sperm and promote their development. Sertoli cells are located within the seminiferous tubules, and play an analogous role to follicle cells in the ovaries.
* LH stimulates the Leydig cells to produce testosterone, which promotes spermatogenesis. Leydig cells are located in the testes, outside of the seminiferous tubules.
* Testosterone further stimulates spermatogenesis by promoting maturation of the sperm after completing meiosis.
* While this doesn’t occur in a monthly cycle as in females, the hormones do interact in a negative feedback cycle when sperm counts get too high (over about 20 million/ml): rising testosterone levels cause Sertoli cells to release the hormone inhibin, which acts on the hypothalamus and pituitary gland to inhibit the release of FSH and LH.  The inhibition causes spermatogenesis to slow down; once the sperm levels are reduced, the Sertoli cells stop releasing inhibin, and the sperm count increases.
  + Difference between Oogenesis vs Spermatogenesis:
* Egg production began during embryonic development and arrested in meiosis until puberty, sperm production doesn’t begin until puberty
* Egg production isn’t completed until fertilization but sperm production is complete prior to ejaculation
* Egg production results in a single cell from each egg stem cell but sperm production results in four sperm from each sperm stem cell
* A screen shot of a chart

  Description automatically generatedSperm production is continuous after puberty, but egg production occurs one-at-a-time at each menstrual cycle

A diagram of different stages of development

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A diagram of different types of egg cells

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1. Explain how various medical interventions affect reproductive cycles and fertilization

**Animal Development I: Fertilization & Cleavage**

1. List the sequence of early events in animal development (fertilization, cleavage, gastrulation, and organogenesis)
   * **Fertilization:** the process of a single sperm cell combining with single egg cell to form a zygote.
   * **Cleavage:**rapid, multiple rounds of mitotic cell division where the overall size of the embryo does not increase. The developing embryo is called a blastula following completion of cleavage.
   * **Gastrulation**: rearrangement of cells in the blastula to create the embryonic tissue layers, which will go on to produce the tissues and organs of the adult animal
   * **Organogenesis**: process of organ and tissue formation via cell division and differentiation

* Last two together make up morphogenesis, which is the biological processes that result in the organisms shape and body organization

1. Identify key structures in/on eggs and sperm, and explain their roles in fertilization
   * Fertilization: process of a single haploid sperm fusing with a single haploid egg, creating a zygote.
   * Egg is the largest cell produced in most animal species
   * Features of egg cells:

* Yolk: the nutrient to support growth of the developing embryo
* Jelly layer/zona pellucida (for mammals): surrounds the egg, a layer composed of glycoproteins (proteins with sugar stuck on them) that release species specific chemoattractant that guide the sperm to the egg. In placental mammals there’s a layer of follicular cells surrounding the zona pellucida.
* Vitelline envelope: second membrane outside the cell’s plasma membrane, what separates the jelly layer from the egg
* Cortical granules: what degrade the proteins that hold the vitelline envelope around the plasma membrane when fertilization occurs
  + Features of sperm cells:
* Head has the DNA, flagellar tail for swimming, mitochondria for power for the sperm to move
* Bindin proteins: binding proteins in the plasma membrane that recognize and bind to receptors on the egg plasma membrane
* Acrosome: digestive enzyme in the head of the sperm that will degrade the jelly layer to allow the sperm to reach the egg plasma membrane
  + Steps of fertilization:

1. Sperm is attracted to and makes contact with the jelly layer/zona pellucida.
2. The interactions between receptors on the sperm cell and glycoproteins on the egg cell initiate the **acrosome reaction**. Digestive enzymes are released from the acrosome in the sperm, and the enzymes destroy the jelly layer/zona pellucida to create a pathway for the sperm to reach the egg
3. The sperm reaches the egg plasma membrane, and the **bindin proteins** on the sperm plasma membrane contact the **bindin receptors**on the egg plasma membrane; this process allows the sperm and egg membranes to fuse. Bindin proteins and bindin receptors are *species-specific*, meaning that the sperm from one species is unlikely to be able to fertilize the egg of a different species.
4. Fusion of the sperm and egg membranes initiates *electrical depolarization* of the entire egg plasma membrane for 10-20 seconds, temporarily preventing any other sperm from fusing with the egg plasma membrane. This membrane depolarization, mediated by an influx of sodium ions, is the **fast block to polyspermy**.
5. The membrane depolarization then initiates a wave of **calcium** released across the plasma membrane.
6. The calcium wave initiates the **cortical reaction** in the egg, where the **cortical granules** fuse with the egg plasma membrane, releasing digestive enzymes that degrade the bindin receptor proteins on the egg membrane. The bindin receptors have two jobs: they are sperm docking sites, and they also hold the vitelline layer against the plasma membrane.
7. Destruction of the bindin receptors in the egg plasma membrane causes the vitelline layer away from the egg plasma membrane, creating the **fertilization envelope.** The fertilization envelope is a barrier that prevents additional sperm from reaching the egg, and is the **slow block to polyspermy**.
8. Diagram of a cell structure

   Description automatically generated with medium confidenceThese events culminate in **egg activation**, causing the egg to recognize that fertilization has occurred and resulting in initiation of development
9. Explain and describe the significance, steps, and features of fertilization and cleavage in early animal development
   * Cleavage cell division can occur every 10 minutes
   * During cleavage, cells divide without growing between divisions
   * The large single-celled zygote divides into smaller cells called blastomeres, after 100 blastomeres have been produced, the embryo is a blastula
   * The blastula is the spherical layer of blastomeres that is considered to be the fist embryonic tissue, called the blastoderm
   * The blastoderm surrounds a fluid or yolk filled cavity called the blastocoel
   * A close-up of a list of cells

     Description automatically generatedMammalian blastula is called blastocyst, which has an inner cell mass (will form the fetus) and out cell layer called the trophoblast (will form portions of the placenta)
10. Differentiate between intrinsic and extrinsic factors determining cell specialization
    * Intrinsic (internal or lineage) information is inherited from the mother cell as a result of cell division

* Because they were present in the cytoplasm of the mother cell, they will be present in the cytoplasm of the daughter cell (this is called cytoplasmic determinants)
* Cytoplasmic determinants are presents in the unfertilized egg before development (or fertilization) even begins
  + Extrinsic (external) information is received from the cell’s surroundings for neighboring cell that tells the cell what it should be
* Induction is an example

1. Explain and differentiate between the roles of cytoplasmic determinants and induction in determining body axes during early animal development
   * lateral-medial (left-right), dorsal-ventral (back-belly), and anterior-posterior (head-feet) axes
   * Body axes of animals are determined during the blastula stage either through cytoplasmic determinants (most invertebrates), yolk polarity (vertebrates with large amounts of asymmetrically distributed yolk, induction (or cell-cell communication) for mammals

* Cytoplasmic determinants: either mRNAs or proteins found in the egg prior to fertilization
  + Asymmetrically distributed
  + The first cleavage will result in different intrinsic information, leading to different cell fates
  + Ex. Bicoid (fruit flies): wherever there is more Bicoid, will become the anterior or head portion of the embryo, wherever there is lowest will become the posterior or tail region
  + Important for protostome and deuterostome development
* Yolk polarity: the yolk is heavier than the egg and sinks to the bottom of the egg due to gravity, which makes the yolk asymmetrically distributed in the egg and the region of the egg with very little yolk (animal pole) will be the head part and the yolk part (vegetal pole) will become the tail structure
* A diagram of a diagram of a sperm cell

  Description automatically generated with medium confidenceInduction: one of the five essential development processes for all animal and plant species

**Animal development II**

1. Explain the significance, features, and consequences of gastrulation and organogenesis in early animal development
   * After cleavage the typical blastula is a ball of cells with a hollow cavity in the middle (the blastocoel)
   * During gastrulation, the cells in the blastula rearrange to form three layers of cells to form the body plan (embryo is called the gastrula)
   * Gastrulation results in:

* Formation of germ layer: organisms can be triploblasts (have endoderm, ectoderm, and mesoderm) or diploblasts (no mesoderm)
* Germ layer will later become differentiated into specialized tissues and organ systems
* Formation of the archentron (embryonic gut)
* Appearance of major body axes, they begin to become visible
* In protostomes, the blastopore becomes the embryo’s mouth; in deuterostomes, the blastopore becomes the embryo’s anus.
* Gastrulation in triploblasts:
* One group of cells move into the blastocoel through an invagination called the blastropore and become the endoderm
* Other cells surround the embryo, forming the ectoderm
* Other group moves between the inner and outer layers to form the mesoderm
* The endoderm cells continue through the interior of the embryo until they reach the other side, creating the continuous tract that will be the archenteron

1. List and describe adult tissue types in animals, and identify major organs arising from each embryonic germ layer, including: epidermal tissue, the nervous system, muscle and skeletal systems, circulatory system, reproductive organs, liver, pancreas, and epithelial lining of the digestive and respiratory systems.
   * The **ectoderm** gives rise to the nervous system the skin epidermis, and the epithelial lining of the mouth and rectum.
   * The **mesoderm** gives rise to muscle cells and skeletal cells, the circulatory system, and the reproductive organs.
   * The **endoderm** gives rise to many internal organs such as the liver and pancreas, and the epithelial lining of the digestive and respiratory systems.
   * Tissues: group of similar cells that work together for a specific task
   * Organs: made up of two or more tissues organized to carry out a particular function
   * Organ systems: group of organs with related functions
   * Tissues that arise from germ layers: **epithelial tissue, connective tissue, muscle tissue, and nervous tissues**

* **Epithelial**: consists of tightly packed sheets of cells that cover surfaces (such as the outside of the body) and line body cavities.
* Ex. Outer layer of skin and internal lining of small intestine
* Tight packing lets them act as barriers to the movement of fluids and potentially harmful microbes
* Top and bottom side, top facing the inside of a cavity or outside of a structure, bottom facing the underlying cells
* **Connective tissue**: consists of cells suspended in some kind of extracellular matrix (“extra”cellular means “outside of” the cell)
* Made up of protein fibers in a solid, liquid, or jellylike ground substance
* Supports and connects other tissues
* **Loose** connective tissues (supports organs and blood vessels and links epithelial tissues to the muscles underneath)
* **Dense** (found in tendons and ligaments, connecting muscles to bones and bones to each other)
* **Adipose** tissue (body fat), bone, cartilage, and blood
* **Muscles tissue**: keeps the body upright, allows it to move, and even pumps blood and pushes food through the digestive tract
  + **Skeletal** muscle: attached to bones by tendons, allows you to consciously control your movements
  + **Cardiac** muscle: found in the wall of the heart (involuntary)
  + **Smooth** muscle: walls of blood vessels, walls of the digestive tract, the uterus, the urinary bladder (involuntary)
* **Nervous tissue**: sensing stimuli (external or internal cues), processing and transmitting information
  + Consists of neurons (basic functional unit of the nervous system/generate electrical signals called action potentials that allow the neurons to convey information very rapidly across long distances) and glia (acts to support neuronal function)

1. Recognize the roles and relationships of the four extra-embryonic membranes in amniotes (birds, reptiles, and mammals)
   * The **amnion**, or inner amniotic membrane, surrounds the embryo itself, enclosing the aqueous environment that the embryo develops in to protect the embryo from mechanical shock and support hydration
   * The **chorion**, which surrounds the embryo and yolk sac, facilitates exchange of oxygen and carbon dioxide between the embryo and the egg’s external environment.
   * The **allantois**stores nitrogenous wastes produced by the embryo and also facilitates respiration in combination with the chorion**.**
   * The **yolk sac**encloses the nutrient-rich yolk and transports nutrients from the yolk to the embryo (note the yolk sac is not the yolk itself, but is the membrane that surrounds the yolk)
   * Mammals that don’t lay eggs still produce amniotic tissues that function as part of the placenta and umbilical cord:

* the **amnion** encloses the fluid-filled cavity to provide an aqueous environment for the developing fetus
* the **chorion** regulates gas exchange
* the **allantois** (not labeled), which functions in waste disposal, is part of the mammalian umbilical cord
* the **yolk sac**, consisting of blood vessels that transport nutrients to the embryo, is also part of the mammalian umbilical cord

1. Describe the roles of induction (cell-cell signaling) and regulation of gene expression in cell specialization and morphogenesis, using the notochord, the neural tube, and somites as examples
   * **Organogenesis**: the germ layers lead to the development of the different organs in the animal body
   * Morphogenesis: the biological processes that results in an organisms shape and body organization

* Morphogens: present in a concentration gradient, inform cell fate based on the concentration
  + Formation of the nervous system originates from *ectodermal*, not mesodermal tissue. During the formation of the neural system, induction causes some cells at the edge of the ectoderm to become epidermis cells. The remaining cells in the center form the neural plate, which will go on to form the nervous system.
  + Diagram of a diagram of a nerve system

    Description automatically generatedBeneath the neural plate is a rod-shaped mesodermal structure called the notochord. The notochord signals the neural plate cells to fold over to form a tube called the neural tube, as illustrated below. During later development, the notochord will disappear (it goes on to form part of the spongy discs between the vertebrae), and the neural tube will give rise to the brain and the spinal cord.
  + Somites: formed from the mesoderm that lies on either side of the vertebrate neural tube. Cells within the somite will migrate to different parts of the body to develop into bone, skeletal muscle, and connective tissue of the skin. The type of a particular tissue will be determined by the specific pattern of induction from nearby tissues (the ectoderm, the neural tube, the notochord, and surrounding mesoderm)
  + As more genes are activated there will be more segmentation

1. Explain the relationship between *Hox* genes and segment identity in animals
   * Differential gene expression: turning on and turning off different genes is what determines a specific cells form and function
   * Differentiation is regulated by induction
   * Regulatory genes: genes that direct the expression of other genes, initiating a developmental “cascade” of changes in gene expression that ultimately lead to proper development of the animal
   * Hox genes: key set of genes involved in differential gene expression and morphogenesis, responsible for determining the general body plan (such as the number of body segments of an animal, the number and placement of appendages, and animal head-tail directionality)

* Each body segment is specified by a specific combination of hox genes, meaning hox genes are responsible for segment identity
* A mutation in a hox gene can result in an extra pair of wings or legs
* Serve as master control genes that can turn on and off large numbers of other genes
* They encode transcription factors that control the expression of numerous other genes
* Hox genes contain the highly conserved amino acid sequence called the homeobox

**Plant reproduction**

1. Compare and contrast the life cycles of angiosperms (flowering plants), gymnosperms (conifers), non-seed vascular plants (ferns), and nonvascular plants (mosses)
   * In alternation of generation there is: multicellular haploid **gametophyte** and the multicellular diploid **sporophyte**
   * **Gamete**: a mature haploid male or female germ cell that is able to unite with another of the opposite sex in sexual reproduction to form a zygote
   * **Spore**: a typically one-celled, reproductive unit capable of giving rise to a new individual without sexual fusion
   * Gametes are always haploid and spores are usually haploid (but always haploid in the plant alternations of generations life cycle)
   * The *gametophyte*makes *gametes*, and the *sporophyte* makes *spores*: The multicellular haploid stage (aka the gametophyte) produces gametes via mitosis which fuse to form a diploid zygote. The zygote develops into a mature multicellular diploid individual (aka the sporophyte), which produces haploid spores via meiosis. The haploid spores then develop into a mature multicellular haploid individual.
   * Differences in life cycles for angiosperms, gymnosperms, non-seed vascular plants, and nonvascular plants:

* Angiosperms: sporophyte dominant, gametophyte is attached to and dependent on the sporophyte
* Gymnosperms: sporophyte dominant, gametophyte is attached to and dependent on the sporophyte
  + Similarities between the two: both produce pollen which delivers sperm to eggs without water + seeds protect the embryo for dispersal
  + Differences between gymnosperms and angiosperms: gymnosperms don’t have flowers or double fertilization but have naked seeds, angiosperms have flowers and double fertilization and fruit covered seeds
* Non-vascular plants/bryophytes: haploid gametophyte is larger than the sporophyte, gametophyte dominated, sporophyte is attached to and dependent on gametophyte
* Seedless vascular plants: sporophyte dominated but the gametophyte is free-living and independent from the diploid sporophyte
  + Similarities: dependent on water for reproduction, produce flagellated sperm that needs to swim to the egg

1. Describe the structures and functions of the flower, seed, and fruit in the angiosperm life cycle
   * Angiosperm reproduction is special because: they have flowers (which attracts animal pollinators), reproduce via double fertilization (adaptation to invest resources for nourishment of the developing embryo, have fruit covered seeds (facilitates seed dispersal)
   * Flower structure:

* The outermost layer consists of **sepals**, green, leafy structures which protect the developing flower bud before it opens.
* The next layer is comprised of **petals**, modified leaves which are usually brightly colored, which help attract pollinators.
* The third layer contains the *male reproductive structures*: the **stamens**; stamens are composed of **anthers**and **filaments**. Anthers contain the **microsporangia,**the structures that produce the **microspores**, which go on to develop into male gametophytes. Filaments are structures that support the anthers.
* The innermost layer contains one or more *female reproductive structures*: the **carpel**; each carpel contains a **stigma**, **style**, and **ovary**. The ovaries contain the **megasporangia**, the structures that produce the **megaspores**, which go on to develop into female gametophytes. The stigma is the location where pollen (the male gametophyte) is deposited by wind or by pollinators. The style is a structure that connects the stigma to the ovary.

A diagram of a flower

Description automatically generated

1. Describe the process, locations, and significance of angiosperm gametogenesis and fertilization, including double fertilization
   * Male gametophyte (pollen grain):

* In angiosperms and gymnosperms
* Pollen is a gametophyte so the multicellular haploid organism that produces the sperm
* Pollen allows for reproduction away from water
* Pollen production is in the microsporangium located in the anthers, which are pollen sacs in which the microspores develop into pollen grains
* Microspores are derived from a diploid cell, which divides by meiosis to create four microspores each of which will ultimately form a pollen grain
* Mature pollen cells contain: 2 cells, a generative cell and a tube cell. Generative is in tube cell
* When pollen reaches the stigma of a flower it undergoes germination:
* Tube cell of the pollen begins growing into the flower stigma through the style and down into the bottom of the ovary, forming a pollen tube (a conduit to deliver sperm to the egg)
* Generative cell migrates through the pollen tube to the ovary for fertilization, dividing to form two sperm cells as it does so
* For successful fertilization, both sperm cells are required
  + Female gametophyte (embryo sac):
* 2 phases:
  + A single cell in the diploid megasporangium in the ovules undergoes meiosis to produce four megaspores (similar to animal gamete production, only one survives)
  + The surviving haploid megaspore will then undergo mitosis without complete cell division to produce an eight nucleate seven cell female gametophyte, which is the embryo sac
* In the embryo sac:
  + Two of the nuclei (polar nuclei) move to the center of the embryo sac and fuse together, forming a single diploid central cell (which will then fuse with a sperm to form the triploid endosperm, that will provide nourishment for the developing embryo
  + Three nuclei position themselves on one the end of the embryo sac and develop into the **antipodal cells**, which later degenerate to provide nourishment to the embryo sac.
  + On the opposite side of the embryo, the nucleus closest to the **micropyle**(the site where sperm enter the embryo sac) becomes the *female gamete*, or **egg cell**
  + The two nuclei on either side of the egg cell will develop into **synergid cells**. The synergids use chemical signaling to help guide the pollen tube for successful fertilization
* Once fertilization happens: diploid zygote will develop into the embryo and the fertilized ovule forms the other tissues of the seed, ovule wall becoming part of the fruit
* A diagram of a cell

  Description automatically generatedOvule is sporophyte and structures within the embryo sac are gametophyte
  + Double fertilization is unique to angiosperms:
* As described above, after pollen is deposited on the stigma, it germinates and grows through the style to reach the ovule. The pollen tube cell grows to form the pollen tube, guided to the micropyle by chemical signals from the synergid cells. The generative cell travels through the tube to the egg and divides mitotically to form two sperm cells. One sperm fertilizes the egg cell, forming a diploid zygote; the other sperm fuses with the two polar nuclei, forming a triploid cell that develops into the **endosperm**, which serves as a source of nutrition for the embryo during development, and also after germination. Together, these two fertilization events in angiosperms are known as **double fertilization**, illustrated below. After fertilization is complete, no other sperm can enter. The fertilized **ovule** forms the **seed**, and the **ovary** become the **fruit**, usually Diagram of a cell structure

  Description automatically generated with medium confidencesurrounding the seed.

A diagram of a plant life cycle

Description automatically generated

1. Predict mechanisms of pollination based on flower characteristics
   * Way a particular plant species is pollinated
   * Mechanism of pollination and the features of the flower are tightly linked: animal pollinated flowers must produce nectar or extra pollen to attract and feed animal and flowers pollinated by abiotic agents must produce a large quantity in order to ensure pollination (there are low chances of success)
   * Features of flowers and their mechanisms of pollination:

* Colored and highly scenter flowers: are pollinated by bees, butterflies, wasps, or flies, which are active during the day and are able to detect bright colors and have a strong sense of smell. Sweet smells attract bees and butterflies and rotting smells attract flies.
  + Many insect pollinated flowers have color patterns in the UV range that only insects are able to see
* White or pale colored and highly scented flowers: pollinated by moths and bats, which are active at night. Light coloring makes them easier to see at night and they tend to smell musky or fruity.
  + Flowers pollinated by bats are larger than those pollinated by moths
* Brightly colors and odorless flowers: tend to be pollinated by birds, who don’t have a strong sense of smell. Flowers tend to have a curved, tubular shape to accommodate a birds beak
* Small green, petal less flowers: tend to be pollinated by the wind, do not produce nectar, but produce excessive quantities of pollen
* Aquatic plants: pollinated by water, the pollen floats and water carries it to another flower

1. Describe the process and significance of seed maturation, dormancy, and germination
   * Seed is analogous with amniotic egg in animal reproduction
   * After fertilization, the zygote enters a temporary period of development, first dividing to form two cells (upper or apical cell and lower or basal cell)
   * Basal cell becomes the suspensor, which eventually makes connection with the maternal tissue but does not become part of the future plant but instead a route for nutrition to be transported from the mother plant to the growing embryo (type of extra embryonic tissue)
   * Apical cell gives rise to the actual embryo that will develop into a plant

* The zygote divides asymmetrically
* Polarity and longitudinal axis are established by the asymmetric division of apical and basal
  + The endosperm will accumulate starches, lipids, and proteins and nourishes the developing cotyledons (embryonic leaves)
* Will serve as nutrient and energy store for embryo development after germination
* Embryonic tissues develop (cotyledons, hypocotyl, and  
  root apex); the root apex and shoot apex are embryonic meristems
* Endosperm and cotyledons accumulate storage products to support future germination

A diagram of a plant

Description automatically generated

* + Desiccation (drying out of the seed) will cause development to pause and the seed to enter into a period of dormancy as it concentrates the seed’s sugars to protect the cell from freezing during the winter months (biological anti-freeze – high sugar content is the reason ice cream stays soft in the freezer)
  + Dormancy: period of no growth and minimal metabolic activity
  + Dormancy allows time for dispersal and growth will resume once the conditions are appropriate for seedling growth, in which the seed will germinate or re-initiate development
  + Once development is reactivated, the developing seedling will rely on the food reserves stored in the cotyledons until the first set of leaves begin photosynthesis. The signal to initiate seed germination is indicator that conditions are favorable for growth and, depending on the species, can include:
* **water**, indicating the start of the rainy season and re-hydrating the seed
* **specific wavelengths of light**, indicating favorable sunlight conditions necessary for photosynthesis and the seed is not buried too far under the soil
* a sustained period of **cold**, indicating that the seed does not germinate until the cold season is over
* **fire**, typical of forest trees, indicating reduced competition from existing tall tree
* **scarification**, or chemical treatment with acids, indicating that the seed has passed through the digestive tract of an animal

1. Predict mechanisms of seed dispersal based on fruit characteristics
   * After fertilization the ovary of a flower will develop into fruit (any structure that develops from an ovary after fertilization)
   * Biological purpose of fruit: seed dispersal, allowing the seed to be spread away from the mother as far as possible
   * Can predict a fruits dispersal mechanism based on structure, composition, and size:

* **Propulsion-dispersed** fruits, such as violets, actually “explode” out of the plant.
* **Wind-dispersed fruits**, such as dandelions, are lightweight and may have wing or parachute-like appendages that allow them to be carried by the wind.
* **Water-dispersed fruits**, such as coconuts, are light or buoyant, giving them the ability to float.
* **Animal-dispersed fruits** may be either have tiny “hooks” all over them so that they attach to passing animals and later fall off in a new location (like sandburs), or very sweet or fatty so that they will be eaten and deposited in a new location in the feces (like blackberries). Fruits dispersed by birds tend to be brightly colored as birds have a highly developed sense of sight; fruits dispersed by mammals tend to be highly scented as mammals have a highly developed sense of smell.

**Plant Development I: Tissue differentiation and function**

1. Recognize relationships between plant embryonic structures and mature plant morphology
   * Auxin: gradient in a plant cell that is a plant hormone that acts like a cytoplasmic determinant, setting up the apical/basal axis
   * Following fertilization of the ovule by sperm, the plant zygote divides asymmetrically:

* Apical or top part of the cell contains a higher concentration of auxin (cell will go on to become the plant embryo)
* Basal or bottom contains little auxin, and will develop into the suspensor (functioning as the umbilical cord, providing nutrients from maternal to embryonic tissue)
  + Apical cell will give rise to the cotyledon, the hypocotyl, and the radicle:
* Cotyledons: embryonic leaves, will become the first leaves of the plants upon germination
  + Monocots have a single cotyledon and dicots have two cotyledons
* Hypocotyl: will become the stem as the plant matures
* Radicle: will become the roots

1. Describe the organization and functions of plant organs (roots, stems, and leaves), and relate morphology to function
   * Seeded plants (angiosperms and gymnosperms): contains two organ systems

* Root system: supports the plants and absorbs water and minerals (usually underground)
* Shoot system: is made up of the stem, leaves, and reproductive parts of the plant (above ground)
  + Seeded plants contain three organs:
* Roots: usually underground with three major functions, anchoring the plant to the soil, absorbing water and minerals and transporting them to the shoot system, as well as storing the products of photosynthesis
  + Tap root systems: grow vertically with smaller lateral roots rising from the tap root (common in dicots)
  + Fibrous root systems: closer to the surface with a dense network of roots, can prevent soil erosion (monocots)
* Stems (the shoot system): usually above ground with a main function of providing structural support to the plant, holding leaves, flowers, and buds as well as connect the roots to the leaves, transporting absorbed water and minerals from the roots to the rest of the plant and transporting sugars from the leaves (site of photosynthesis) to desired locations
  + Plant stem structures:
    - Nodes: points of attachment for leaves and flowers
    - Internodes: regions of stem between two nodes
    - Apical bud: at the tip of the shoot and contains apical meristem, the site of new growth above ground
    - A plant with a pink flower and roots

      Description automatically generatedAxillary buds: may present where a leaf meets a stem, sites where branches or flowers may be produced
* Leaves: main site of photosynthesis
  + Leaf structure:
    - Petiole: attaches the leaf to the stem
    - Veins: bundles of vascular tissue that run through the leaf, they carry water and nutrients and also provide structural support to the leaf

A diagram of a leaf

Description automatically generated

A diagram of tissue with green rectangles

Description automatically generated

1. Describe the features and functions of plant tissues, identify and describe cell types associated with each tissue, and relate cell and tissue morphology with function
   * Three main types of tissue: dermal, vascular, and ground tissue (each of the organ systems contain all three)

* Dermal tissue: covers and protects the plant, controls gas exchange and water absorption
* Vascular tissue:  transports water, minerals, and sugars to different parts of the plant. Vascular tissue is made of two specialized conducting tissues: xylem, which transports water and also provides structural support, and phloem, which transports sugars from sites of photosynthesis to other parts of the plant. The xylem and phloem *always*lie adjacent to each other in a vascular bundle
* A diagram of a plant

  Description automatically generatedGround tissue: carries out different functions based on the cell type and location in the plant, including photosynthesis, structural support for the stem and the vascular tissue, and storage for water and sugars.
  + All cells have primary cell walls (which are flexible and can expand) and some have secondary cell walls (typically composed of lignin)
  + Cells in dermal tissue:
* Epidermal cells: single layer of epidermal cells which provide protection and have other specialized adaptations in different plant organs
  + Coated with a waxy cuticle to prevent water loss (in stems and leaves)
  + No waxy cuticle (in roots)
* Guard cells: permit gas exchange for photosynthesis and respiration, around the stomata in the epidermis of the leaf and stem and control its opening and closing (regulating the uptake of carbon dioxide and the release of oxygen and water vapor)
* Root hairs: microscopy extensions of root epidermal cells, increasing the surface area of the root
* Trichomes: spiky or hair like structures on the epidermal surface that help to reduce transpiration, increase solar reflectance, and store compounds for defense of the leaves
  + Cells in vascular tissue:
* Vascular tissue is made up of xylem (water) and phloem (sugar and other organic compounds) (always next to each other)
  + In stems: xylem and phloem form a vascular bundle
  + In roots: vascular stele or cylinder
* Xylem tissue transports water and nutrients from the roots to different parts of the plant (composed of vessel elements and tracheid’s=tubular elongated cells that conduct water)
  + Tracheids in all types of vascular plants
  + Vessel elements are only in angiosperms and a few other specific plants
  + Tracheids and vessel elements are arranged end to end with perforations called pits between adjacent cells to allow for free flow of water from one cell to the next
  + Have secondary cell walls with lignin (provide structural support for the plant)
  + Dead at functional maturity
* Phloem tissue transport organic compounds from the site of photosynthesis to other parts of the plant, consists of sieve cells and companion cells
  + Sieve cells: sugar and other organic compounds throughout the plant body, arranged end to end with pores called sieve plates to allow movement between cells
  + Companion cells: adjacent to sieve cells and share cytoplasm (provides metabolic support and regulation)
  + Alive at functional maturity
  + A close-up of a plant cell

    Description automatically generatedCells in ground tissue: all other tissue that isn’t dermal or vascular. Include parenchyma (carries out photosynthesis in leaves and performs sugar storage in roots), collenchyma (supports the stems and leaves in area of active growth), and sclerenchyma (supports the stem and leaves in areas where growth has ceased)
* **Parenchyma** are the most abundant and versatile cell type in plants (if you stumble upon a new type of plant cell that you’ve never heard of, it’s a good bet that it’s a subtype of parenchyma cell). Their primary cell walls are thin and flexible, and most lack a secondary cell wall.
  + Most of the tissue in leaves is comprised of parenchyma cells, which are the sites of photosynthesis; and parenchyma cells in the leaves contain large quantities of chloroplasts for photosynthesis.
  + In roots, parenchyma are sites of sugar or starch storage, and are called pith (in the root center) or cortex (in the root periphery).
  + Parenchyma cells comprise a specialized cortex tissue in roots called**endodermis**, which is found only in the roots and and serves as a checkpoint for materials entering the root’s vascular system from the environment. A waxy substance is present on the walls of the endodermal cells. This waxy region, known as the Casparian strip, forces water and solutes to cross the plasma membranes of endodermal cells instead of slipping between the cells.
  + Parenchyma can also be associated with phloem cells in vascular tissue as parenchyma rays.
  + Even though they are characterized as ground tissue, parenchyma cells are *totipotent*, meaning they can divide and differentiate into *all cell types* of the plant; parenchyma are the cells that are capable of producing roots from a cut stem.
* Collenchyma: have thicker primary cells walls than parenchyma, and also lack a secondary cell wall.
  + They are long and thin cells that retain the ability to stretch and elongate.
  + Their ability to elongate helps them provide structural support in growing regions of the shoot system; they are highly abundant in elongating stems.
  + If you have ever eaten celery, you have encountered collenchyma cells; they are the “stringy” bits found in celery.
* Sclerenchyma: cells have secondary cell walls composed of **lignin**, a tough substance that is the primary component of wood.
  + Schelrenchyma cells cannot stretch due to their secondary cell wall, and they provide important structural support in mature stems after growth has ceased.
  + Schlerenchyma cells are dead at functional maturity.
  + Sclerenchyma are found in apple cores and they give pears their gritty texture; we use sclerenchyma fibers to make linen and rope.

A diagram of cells and cells

Description automatically generated with medium confidence

1. Differentiate between monocot and eudicot body plan characteristics, including organization of the vascular and ground tissues in stems and roots

A diagram of a plant

Description automatically generated

**Plant Development II**

1. Recognize the relationship between meristems and indeterminant growth, and differentiate between primary and secondary growth
   * **Indeterminant growth**: plants will continue to add new organs (leaves, stems, roots) as long as they have access to the necessary resources
   * Plants are able to grow indeterminately due to specialized tissues called meristems
   * **Meristems**: regions of continuous cell division and growth

* Are like stem cells, undifferentiated and continue to produce cells that quickly differentiate or specialize and become permanent tissues (either dermal, ground, or vascular)
  + Primary vs Secondary growth:
* Primary: getting taller or longer
  + Controlled by root meristems or shoot apical meristems
* Secondary: get wider
  + Two lateral meristems (vascular cambium and cork cambium)

1. Differentiate between apical and lateral meristems. and explain their different roles in plant growth
   * Apical meristems: meristematic tissue located at the tips of stems and roots, enabling a plant to extend in length
   * Lateral meristems: facilitate growth in thickness or width in a maturing plant (also called cambia/cambium)
   * Intercalary (basal): in monocots at the bases of leaf blades and at nodes, or where the leaves are attached to the stem (enables leaf blades to increase in length)
   * **Primary growth in roots**:

* When the plant embryo emerges from the seed, the radicle of the embryo forms the root system
* Tip is protected by the root cap (exclusive to roots)
  + Continuously replaced as it is continuously damaged as the roots grows through the soil
* Behind the root tip there are three zones:
  + Zone of cellular division: location where new cells are being generated by mitotic cell division (driven by the activity of the apical meristem located immediately behind or under the root cap)
  + Zone of cellular elongation: where new cells are growing, elongating to add length to the root (uptake of water will stretch the cell and increase their size)
  + Zone of cellular maturation: location where newly elongated cells complete their differentiation into either dermal, vascular, or ground tissues
* Lateral roots that branch from main tap root:
  + Originates from meristematic tissue in the pericycle (a layer of parenchyma cells (ground tissue cell) that surrounds vascular cylinder in the center of the root)
  + Lateral roots have their own form of primary growth as they continue adding length
  + **Primary growth in shoots**:
* Result of rapidly dividing cells in the apical meristems at the shoot tip, subsequent cell elongation is primary growth
* Most primary growth for stems occurs at the apical bud instead of axillary buds
* Apical dominance: where the apical bud prevents the growth of axillary buds that form along the sides of branches and stems

1. Explain how the two lateral meristems contribute to secondary growth in woody stems
   * Secondary growth is controlled by lateral meristems in both stems and roots
   * Lateral meristems include the vascular cambium and cork cambium in woody plants

* Secondary growth, or wood, is noticeable in woody plants; it occurs in some dicots but occurs very rarely in monocots.
  + **Secondary growth in stems**:
* Vascular cambium contributes to the vast majority of secondary growth
* Vascular cambium is located between the primary xylem and primary phloem within the vascular bundle (which are arranged in a ring near the periphery of dicot stems with xylem in the interior and phloem in exterior)
* Cells of the vascular bundle divide and form secondary xylem (tracheid’s and vessel elements) and secondary phloem (sieve elements and companion cells)
* New cells appear between the primary xylem and primary phloem on either side of the cambium with the secondary xylem towards the inside of the cambium ring and secondary phloem towards the outside of the cambium ring
  + Secondary xylem cells contain lignin which is a primary part of wood and provides strength and structural support
  + Xylem and pith (ground tissue in the center of the stem) form the wood of a woody stem
* **Cork cambium**:
  + Outermost lateral meristem
  + Cork cambium produces cork cells, which contain a waxy substance that can repel water
  + Phloem and cork cells form the bark which protects the plant against physical damage and helps reduce water loss
  + Produces a layer of cells known as phelloderm which grows inward from the cambium
  + **Periderm**: cork cambium, cork cells, and phelloderm
    - Diagram of a plant cell showing different stages of growth

      Description automatically generatedSubstitute for the epidermis in mature woody-stemmed plants

1. Identify and classify the components woody stems derived from secondary growth
   * A new layer of xylem and phloem are added by the vascular cambium each year during the growing season creating new wood and bark

* Wood: xylem and pith (the ground tissue found within the center of a woody stem)
  + Everything from the vascular cambium toward the interior of the woody stem
* Bark: phloem and cork
  + Everything from the vascular cambium toward the exterior of the woody stem
* Over time, the wood gets larger in diameter and the bark stays the same
  + As the tree grows, it adds a new layer of xylem every year toward the inside of the ring of the vascular cambium
  + As it grows wider, the interior xylem layers eventually fill with resin and become nonfunctional for carrying water but provide support
  + The interior, nonfunctional xylem is called heartwood and the newer functional xylem is sapwood
  + A new layer of phloem is added to the exterior of the ring of vascular cambium and the cork cambium (outside the vascular cambium) is also adding new layers of cork
  + Exterior layer of phloem is crushed into the bark
  + So there is many layers of old nonfunctional xylem but only a small amount of older phloem
  + Annual growth rings:
    - Early wood: during spring, cells of secondary xylem have a large internal diameter and their primary cell walls are relatively thin
    - Late wood: during the fall season, secondary xylem develops thickened cell walls
    - An examination of the number of annual rings and their nature (such as their size and cell wall thickness) can reveal the age of the tree and the prevailing climatic conditions during each season.