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CHAPTER 1

INTRODUCTION TO DEVELOPMENTAL BIOLOGY

Animals and plants undergo a series of progressive changes; taking on the successive forms that characterize its life cycle is called as **development** (Figure 1). In most of organisms development is a life long continuous process, starts with single cells, assumes multicellularity and ends with life. The gradual developmental strategy is known as **epigenesis**. An animal in its earliest stages of development is an **embryo**. Sometimes a protective structure is present that covers an embryo is **uterus**. An embryo obtains its food from its mother directly or indirectly (by way of nutrients stored in the egg) as feeding activity is absent in embryo. Series of embryonic stages results in the birth of the new, independent organism.

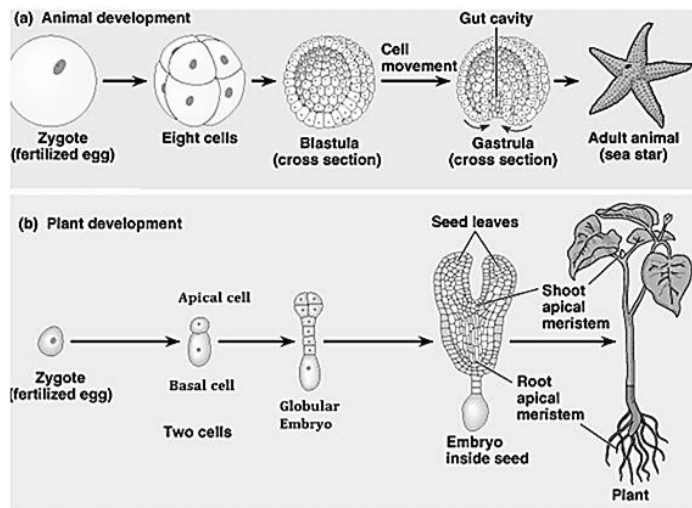


Figure 1: Stage of development in animals and plants

The main processes involved in the embryonic development are: Growth, cell division, differentiation, tissue patterning, and morphogenesis. **Cell growth** means increase in size of cell due to accumulation of cytoplasmic material while **cell division** includes increase in number of cells by mitosis and cytokinesis. **Cell differentiation** relates specifically to the formation of functional cell types such as nerve, muscle, secretory epithelia etc. **Tissue patterning** or **regional specification** refers to the processes that create spatial pattern in a ball or sheet of initially similar cells. **Morphogenesis** leads to the formation of three-dimensional shape and **tissue growth** involves both an overall increase in tissue size, and also the differential growth of parts (allometry) which contributes to morphogenesis. Animal development at molecular level depends on spatial and temporal patterns of maternal to embryonic gene expression, gradually specifying embryonic territories and executing their differentiation.

1.1 EVOLUTION OF DEVELOPMENTAL BIOLOGY

Development of living organisms, including humans, has always fascinated mankind. Consequently, many beliefs, scientific theories and explanations have been put forward to explain principles and mechanism of developmental biology. It is fascinating to look at the historical events that saw emergence and demolition of a variety of beliefs and theories that culminated in establishment of developmental Biology as we understand and practice today.

Investigation on animal development is believed to have begun in the 4th century BC with simple observations of egg and embryos that could be seen with the naked eye. Most of work started to answer a very old question: How is an entirely new human being generated following intercourse?

Hippocrates (460–370 years BCE) believed that man and woman each contributed semen that mixed in the uterus to form the embryo while **Aristotle** (384–322 years BCE) believed that woman merely provided fertile ground for the male seed to grow.

Oscar Hertwig discovered fusion of sperm and egg nuclei during fertilization in sea urchins in 1876, providing a conceptual basis for genetic inheritance and settled the long-standing debate on the role of the egg and sperm in generation of new life.

Aristotle (384–322 years BCE) was the first to record differences in life cycles of animals. He observed that some animals are born from eggs (oviparity) as seen in most invertebrates and vertebrate like frogs and birds. He also observed that in some animals, embryos were born directly as young ones, phenomenon termed as **viviparity** (example-mammals except for monotremes). He also observed that some animals were born from eggs that hatched within the body, phenomenon termed as **ovo-viviparity** (example-some snakes and sharks).

Aristotle also recorded two types of division patterns in the fertilized egg as the embryos undergo cleavage namely:

1. **Holoblastic** or complete division where the entire embryo divides to form smaller cells as seen in frog and mammals, and
2. **Meroblastic** or partial division pattern of division where only a part of the fertilized egg divides and the rest provides nutrition for the embryo as seen in the chick.

1. Theory of epigenesis and preformation:

Aristotle while working on the development of chick embryo, was the first person to propose **the theory of epigenesis** ('determination/ upon formation') for the development of organisms. According to the epigenesis theory, new structures develop progressively in the embryo during development. Thus, according to this theory there was no preformed tissue or organ in the embryo at the beginning of development.

Another contemporary theory for development was theory of preformation. This theory advocates that organisms develop from miniature versions of themselves, called the **homunculus** (Figure 2). According to the preformation theory, all the parts in the embryo were existed within the germ cell of one of its parents, prior to fertilization and this would grow and enlarge into its full form during gestation until ready to be born. The Preformationists were thus either spermists or ovists. Spermists believed that the homunculus existed in the sperms while the ovists believed they were contained in the eggs. Pythagoras is one of the earliest thinkers credited with ideas about the origin of form in the biological production of offspring. It is said that he originated "spermism", the doctrine that fathers contribute the essential characteristics of their offspring while mothers contribute only a material substrate.

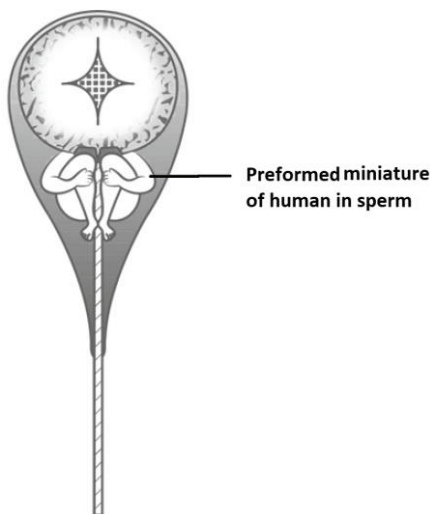


Figure 2: Homunculus – a miniature of organism contained within sperm

In 1651, **William Harvey** published "On the Generation of Animals", a seminal work on embryology asserted, that **ex ovo omnia**—all animals come from eggs. Because of this assertion in particular, Harvey is often credited with being the father of ovist preformationism. He was the first to see the blastoderm of the chick which is the clear, yolk free germinal disc, also called the blastodisc and is in the form of a single layer of embryonic epithelial tissue and gives rise to the chick embryo. William Harvey saw the red dots of pooled blood that arose before the formation of the heart or vessels.

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Leeuwenhoek in 1679 stated that the astonishing activity of the spermatozoa testified that they not only had souls, but that they had complex anatomic structures, there may be as many parts in the sperm as in the human body itself. Leeuwenhoek's presumption of the preformed man or animal within the spermatozoon was more explicitly articulated in 1685, the same year as his commitment to the spermatozoon's living and persisting soul.

Christian Pander (1794-1865) first recognized the existence of three germ layers (ectoderm, mesoderm, and endoderm) in the chick embryo. He also wrote about the interdependence of these layers in forming the embryo. A few years later **Martin Rathke** (1793-1860), another embryologist discovered layers of cells similar to what Pander had described in the crayfish and put forth the idea that three germ layers were not only found in vertebrates but also in invertebrates.

Oscar Hertwig discovered fusion of sperm and egg nuclei during fertilization in sea urchins in 1876, providing a conceptual basis for genetic inheritance and settled the long-standing debate on the role of the egg and sperm in generation of new life. Discovery and understanding of Mitosis by **Fleming** in 1882 was a great step forward towards understanding growth and development. Johannes Sobotta accurately drew pronuclear fusion in mouse in 1895 (Figure 3).



Figure 3: Drawing representing pronuclear fusion in mouse

2. Recapitulation theory or Meckel-Serres law

In 1808, Meckel published his recapitulation theory in *Beyträge zur vergleichenden Anatomie* [Contributions to Comparative Anatomy]. Meckel believed that throughout **ontogeny** (life history of individual), embryos pass through successive stages that represent the adult forms of less complex organisms.

He said that more complex organisms went through developmental stages that chronologically replayed the **scala naturae**, a hierarchical system of classification that places the least complex organisms on the bottom of the classification and the more complex organisms on the top. Later, Meckel's theory was termed the **Meckel-Serres law**, because Antoine Étienne Reynaud Augustin Serres, a physician in France, independently published a similar theory in 1821.

3. Von Baer Laws of Embryology or Development

In 1828, while studying the patterns of embryonic development of animals at the University of Königsberg, Germany, Karl Ernst von Baer, responded to Johann Friedrich Meckel's recapitulation theory and proposed four laws of animal development, which came to be called **von Baer's laws of embryology**.

Von Baer tried to reject Meckel and Serres's theory because he argued that this theory of development was too linear. Von Baer believed that instead of passing through the linear stages of the *scala naturae*, animal embryos started from one, or a few, shared basic forms and then developed in a branching pattern into increasingly different looking organisms.

Von Baer work was based on the germ layer theory of development (ectoderm, mesoderm, and endoderm) as a principle in a variety of species, laying the foundation for comparative embryology. Von Baer described his laws in his book *Über Entwicklungsgeschichte der Thiere*.

They are a series of statements generally summarized into four points as follows

1. General characteristics of the group to which an embryo belongs develop before special characteristics.
2. From the most general forms the less general are developed, and so on, until finally the most special arises.
3. Every embryo of a given animal form, instead of passing through the other forms, rather becomes separated from them.
4. Fundamentally, the embryo of a higher animal form never resembles the adult of another animal form, such as one less evolved, but only its embryo.

Von Baer's first two laws try to explain how animal embryos develop and whether or not they progress from pre-formed structures. During the seventeenth and eighteenth centuries, there had been a debate between two groups of researchers in embryology. One group, the epigenisists, argued that organisms start from unformed material and slowly progress to become more complex organisms. The other group, the preformationists, argued that a fully formed organism exists from the beginning of ontogeny, and then merely grows as ontogeny proceeds.

Von Baer's **first law** states that the general characters of an animal group appear earlier in the embryo than the specialized characters do, which contradicted pre-formationist theories.

Von Baer's **second law** states that embryos develop from a uniform and non-complex structure into an increasingly complicated and diverse organism.

For example, a defining and general characteristic of vertebrates is the vertebral column. This feature appears early in the embryonic development of vertebrates. However, other features that are more specific to groups within vertebrates, such as fur on mammals or scales on reptiles, form in a later developmental stage. Von Baer argued that this evidence supporting epigenetic development rather than development from preformed structures. He concluded from the first two laws that development occurs through epigenesis, when the complex form of an animal arises gradually from unformed material during development.

Von Baer used the third and fourth laws to counter the recapitulation theories of Meckel and Serres. As mentioned, these theories posit that as the ontogeny of an animal embryo progresses, the embryo's different stages of development represent lower animals' adult forms. For example, according to the recapitulation theory, the early human embryos have structures similar to gill slits, and thus that early stage represents the form of adult fish, which also have gill slits.

Von Baer's **third law** states that animals from different species start out similar and become more dissimilar from one another as ontogeny proceeds. As an example, von Baer discusses the embryos of fish, frog, bird and human, all of which look similar to each other in the early stages of their development. As they grow, however, they look increasingly different from one another. The embryo of one species never resembles the adult of another species. Instead of recapitulating other animals' adult forms, von Baer's third law theorized that animal embryos diverge from one or a few shared embryonic forms (**Figure 4**).

The **fourth law** states that the stages of development in more complex animals never represent the adult stages of less complex animals; they resemble only the embryos of less complex animals.

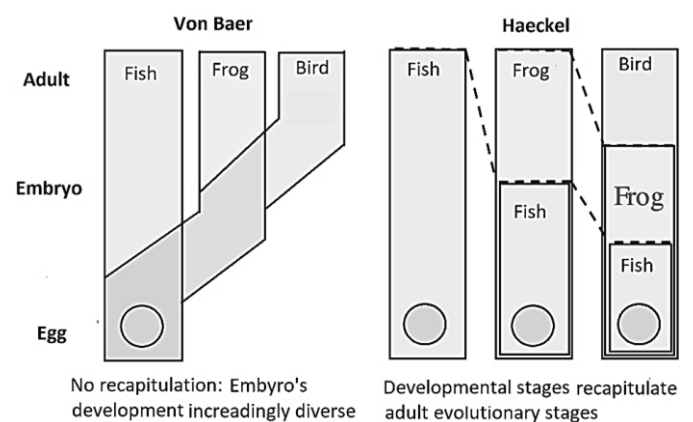


Figure 4: Comparison of Von Baer and Haeckel concept for early embryological development

4. Haeckel Biogenetic Law

In 1866, Ernst Haeckel proposed a theory of recapitulation called the **biogenetic law**, which states that **ontogeny repeats phylogeny**. Unlike the Meckel Serres interpretation of recapitulation, Haeckel's form of recapitulation proposed that embryos pass through the chronological stages of their species' evolutionary ancestry rather than through the scala naturae. Haeckel said that stages during the ontogeny of organisms replay that organism's evolutionary ancestry. He popularized this theory when he synthesized theories of ontogeny with Charles Darwin's 1859 theory of the evolution of species via natural selection; more than thirty years after von Baer had proposed his laws of embryology.

Given that Haeckel's theory was of linear development, similar to Meckel's, von Baer was no more convinced by Haeckel's theory than he was by Meckel's. Furthermore, von Baer did not accept that all species shared a common ancestor. Despite von Baer's objections to Haeckel's biogenetic law and recapitulation in general, the biogenetic law persisted in biology until the turn of the twentieth century when new experimental and comparative evidence rendered it untenable.

The tools and techniques used by early embryologists were simple. Embryological studies involved the use of moulds made of wax or glass strips, direct observation of embryos of various animals, and their manipulation with the help of glass needles which were also used to move and pick embryos. Glass pipettes were also used to pull the embryo by narrow tubes for transfer. Embryologists of that time faced a difficult task in manipulating the embryos and ensuring their survival without them being infected, before they could be isolated, removed and transplanted. Later on with the development of better tools and microscopes with better resolution the "Era of Experimental Embryology began".

5. Concept of Mosaic Development

August Friedrich Leopold Weismann (1834-1914), the German biologist, proposed a model of development in which he assumed that the nucleus and cytoplasm of the zygote contained some special factors or **determinants**. He proposed that during cleavage these determinants would be unevenly distributed in the dividing cells and so could control future development. The fate of each cell according to him was, therefore, predetermined in the egg by these factors. He called this type of **mosaic development**.

His theory was supported by the experiments conducted by the German Zoologist, **Wilhelm Roux** (1850-1924), in late 1800s on frogs. Wilhelm Roux in his experiments destroyed one of the blastomeres of the frog embryo after the first cleavage by using a hot needle. He found that the remaining blastomere formed half of the embryo (**Figure 5**).

He thus, concluded that development was based on **mosaic** mechanism and the cells have their characteristic fate determined at each cleavage.

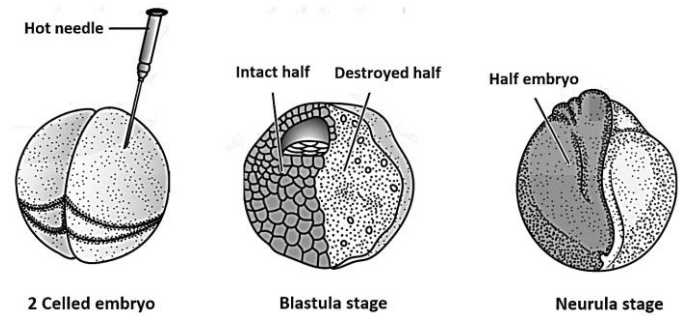


Figure 5: Roux experiment demonstrating mosaic development.

6. Concept of Regulative Development:

In 1891 **Driesch** performed an important experiment: the separation of developing sea urchin blastomeres. He discovered that if the sea urchin blastomeres were separated at the 2-cell stage, two complete but smaller than normal sea urchins would develop. This suggested that the fate of each cell is not already fixed at the 2-cell stage, as Wilhelm Roux had suggested, and that the fate of a cell is determined by its relationship to the whole. These results and interpretations contrasted sharply with results obtained by Wilhelm Roux in his 1888 study of the two-cell frog egg.

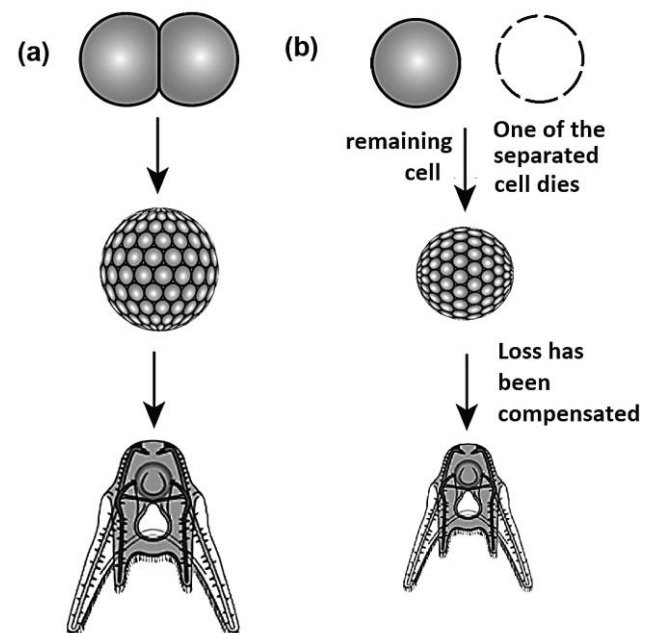


Figure 6: Driesch's Experiment with sea urchin blastula that demonstrated regulative development (a) normal development of sea urchin larva from two cell stage; b) separation of cells at two cell stage resulted in the death of one cell but the other survived to develop into a fully formed smaller larva.

Driesch disagreed, with Roux concept of mosaic development and he suggested that development must involve the power to regulate in response to changing environmental conditions. Such a type of development where embryo has the ability to restore normal development even when some part is missing is termed as **regulative development**.

6. Concept of Induction and Spemann Organizer

The major advancement in experimental developmental biology was due to work by Mangold and Spemann. Hilde Mangold was a PhD candidate who conducted the organizer experiment in 1921 under the direction of her graduate advisor, Hans Spemann at the University of Freiburg in Freiburg, Germany. The discovery of the Spemann-Mangold organizer introduced the **concept of induction** in embryonic development. **Induction** is the process by which the identity of certain cells influences the developmental fate of surrounding cells. Spemann also developed the microtools needed for early experimental embryology, namely glass needles and micropipettes.

Prior to the Spemann-Mangold organizer experiment, Spemann had focused on constricting salamander eggs at the blastopore lip by tying single strands of his baby son's hair around the tiny eggs. Spemann observed that when the hair tightly constricted the eggs at the dorsal end, across the blastopore lip, two embryos developed. Spemann also tested the degree to which constricting the embryo with hair led to different levels of conjoinment. For example, when Spemann constricted the eggs only a little, two heads formed, but if he pulled the hair strand tighter, the embryos developed separate heads and sets of forelimbs. However, when Spemann conducted the same experiment but separated the dorsal end from the ventral end by constriction, only the dorsal end developed, while the other half was left in a vegetative state.

On basis of these initial experiments, Spemann investigated how cell fates were determined during embryogenesis. Spemann was particularly interested in exploring the mechanism of neural plate induction. The neural plate is the embryonic structure that gives rise to the central nervous system during development. To explore neural plate induction, Spemann first performed a transplant experiment that was nearly identical to the later organizer experiment. Spemann transplanted the blastopore lip from one newt gastrula into another, and noticed a second notochord that developed at the site of transplantation. However, the newts were of the same species and it was difficult to determine whether the host tissue or transplanted tissue was acting to create the second nervous system.

To assess the origin of blastopore Spemann conducting **transplantation experiments** between different newt species of the same genus. The eggs from one newt species were pigmented (*Triturus taeniatus*), while eggs from the second species of newt were unpigmented (*Triturus cristatus*), allowing for visual identification of which tissues gave rise to features observed. The transplantation of ectoderm cells from one species (*Triturus cristatus*) at a distance from the blastopore of a second newt's gastrula (*Triturus taeniatus*) revealed that the transplanted tissue was progressively pulled towards the blastopore lip.

Spemann realized that the cells at the lip of the blastopore were invaginating inward. Thus the ectoderm undergoing neural differentiation would be sitting atop mesoderm that formerly comprised the blastopore lip. The blastopore lip was therefore composed of pre-mesodermal cells that initiated the invagination of surrounding cells in a process called gastrulation, which gives rise to the three embryonic germ layers (ectoderm, mesoderm, and endoderm).

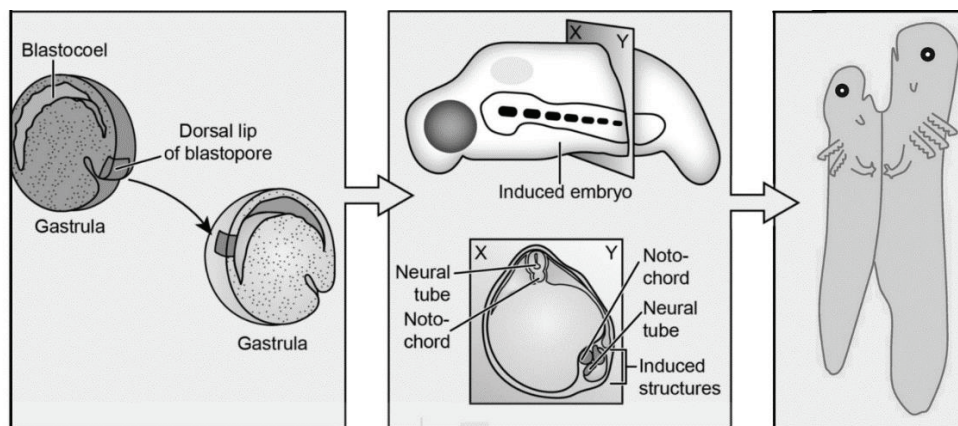


Figure 7: Spemann and Mangold experiment demonstrated induction of a new main body axis by the organizer region in early amphibian gastrula. (a) dorsal lip of blastopore from unpigmented species grafted on the blastocoels roof of a pigmented species; (b) a secondary embryo is induced. (c) two conjoint embryo joined at ventral side.

In 1921, Spemann assigned **Mangold**, to conduct a cross-species transplant of blastopore lips between different newt species. Mangold used the microtools developed by Spemann to excise the blastopore lip of the unpigmented *Triturus cristatus* egg, and transplant it under the ectoderm of a pigmented *Triturus taeniatus* newt egg. This graft, nowadays referred to as the Spemann organizer (also the Spemann–Mangold organizer) had two effects. It induced the formation of neural tissues (neuralization), from the ectoderm that would have generally formed the skin (**Figure 7**). Furthermore it caused dorsalization of the ventral mesoderm, leading to the formation of somites. The ultimate result was what appeared to be two embryos conjoined at the gut.

Work of Spemann and Mangold showed that, in the earliest stages, the fate of the embryonic parts is not determined and if a piece of presumptive skin tissue is excised and transplanted into an area of presumptive nervous tissue, it will form nervous tissue, not skin. It provided the first unambiguous evidence that cell and tissue fates can be determined by signals received from other cells.

This experiment therefore, demonstrated the existence of an organizer that instructs both neuralization and dorsalization, and showed that cells can adopt their developmental fate according to their position when instructed by other cells. Hans Spemann received the **Nobel Prize** in Medicine in 1935 for his work in describing the process of induction in amphibians.

The techniques used to discover the Spemann-Mangold organizer had limitations. The technique for transplanting the organizer involved surgery at a cellular scale, and it demanded great precision. When possible, transplanting was difficult, and many things could not be transferred under the surface of the ectodermic layer because it is only one cell thick in many places. The fact that many materials could not be transplanted kept scientists from testing the inductive capacity of other cellular materials on the embryo. The Eimsteck method circumvented that limitation.

The **Eimsteck method** consists of using the glass and hair microsurgical tools developed by Spemann to plant material inside of the blastocoels of a developing embryo in either the blastula or early gastrula stage. This technique insures that material need not fuse with or adhere to the ectodermic layer. It simply passes through the ectoderm into the cavity beneath, where it can affect the embryo. The insertion wound also heals quickly, leaving the foreign material within the developing embryo to affect change.

Hanns Bruno Geinitz transplanted a Spemann-Mangold organizer into developing blastocoels using the Eimsteck method, which induced embryos like the ones obtained in Spemann and Mangold's original experiments.

Geinitz expanded on the original organizer experiment by transferring organizers from frogs and toads into salamander gastrulae. Geinitz called this type of transfer **xenoplastic** because it involved transplant of cells from a different genus, as opposed to heteroplastic, which involved cross-species transfers like those used by Spemann and Mangold.

Although it was initially proposed that the Spemann-Mangold organizer induced differentiation of the central nervous system, more recent mechanistic examinations have revealed more complicated genetic interactions. Embryologists have determined that the presence of the Spemann-Mangold organizer impedes signaling to the overlying ectoderm. Instead of becoming skin cells, the organizer-affected ectoderm cells become central nervous system tissue.

In 1992, **Richard M. Harland and William C. Smith** at the University of California, discovered a protein integral to cellular induction at the Spemann-Mangold Organizer. As the protein was essential for neural development and eventually the formation of the head, the scientists called it **noggin**.

Since that discovery, the collective work of many experimental embryologists has revealed patterns of genetic interactions. The developing blastula secretes **bone morphogenetic protein-4 (BMP-4)** from the ventral side of the embryo, opposite the organizer. BMP-4 diffuses throughout the blastocoel and induces skin cells where it binds to ectodermal cells. However, the organizer blocks BMP-4 from binding to the surrounding ectoderm by secreting the proteins chordin and noggin. Chordin and noggin bind to BMP-4 in the organizer-affected area to prevent BMP-4 from binding to ectoderm receptors. Instead of becoming skin cells, the ectodermal cells in the area of the organizer take the default path of becoming central nervous system tissues.

7. Modern Approach to Study Developmental Biology

During middle of the 20th century, the scientific discipline of embryology began to emerge as the modern discipline of developmental biology. As is true for other disciplines in biology, knowledge of animal development advanced: (i) as new techniques for experimentation were invented and (ii) with the progress in knowledge of other branches of biology such as cell biology genetics, and especially molecular biology with the discovery of DNA, and the processes of transcription, translation and gene regulation.

Genetic approach to development, revolutionized developmental biology. Which genes were causing which morphological changes and how these genes were controlled to express at certain stages of development became an exciting subject for research for many biologists.

E.B. Lewis (1954) performed genetic studies on a homeotic mutation – **Bithorax** in *Drosophila* and found that loss in function of this gene leads to halteres get transformed into posterior pair of wings.

In 1988, **Nüsslein-Volhard** and **Eric F. Wieschaus** identified the first described **morphogen**, a protein coded by the gene **bicoid** in flies. In 1995, along with Eric F. Wieschaus and Edward B. Lewis, she received the Nobel Prize in Physiology or Medicine for the discovery of genes that establish the body plan and segmentation in *Drosophila*. Nüsslein-Volhard also investigated the genetic control of embryonic development to zebrafish, further generalizing her findings and helping establishing zebrafish as a model organism for studies of vertebrate development.

The field of “Developmental Biology” has changed to very large extent over the past four decades. While genetic analysis had been main focus in the 1980s and continues to be major area for investigations, the introduction of **green fluorescent protein** (GFP) in the 1990s has helped us to look into living, developing embryos, and see how cells form tissues and how organ morphogenesis proceeds in real time. Modern molecular techniques allow the manipulation and study of how proteins function in real time during different stages of development.

1.2 ANATOMICAL POSITIONS AND PLANES

General terms such as “top” and “bottom” or “up” and “down” or “front” and “back” will have common meaning only if everyone starts with a universal standard. In anatomy and developmental biology this standard is the anatomic position, which is a standing or erect position with the palms

of the hands facing forward (**Figure 3a**). In this position, a structure located toward the front of the human body is referred to as **anterior**, while a structure located toward the back is referred to as **posterior**. “**Dorsal**” (back) is also used to describe the back, while “**ventral**” (belly) is used to describe the front of the body. A structure can be “**superior to**” (above) or “**inferior to**” (below) another structure in any part of the body. Terms with similar meaning are **cranial**, which refers to the region of the head, and **caudal**, which refers to the region of the tail. The term **medial** pertains to structures located toward the middle or median longitudinal axis of the human body, while lateral structures are situated more toward the side (**Figure 8a and 8b**). **Superficial** means closer to the surface, or skin, and **deep** refers to farther away from the surface of the body (**Table 1**).

The body of most of higher animals can be dissected with reference to three planes—**sagittal**, **transverse**, and **coronal**—either by means of imaging technologies such as computer axial tomography (CAT scanning), magnetic resonance imaging (MRI) or by dissection. A plane is two dimensional, such as superior/inferior or anterior/posterior. A section is a cut through a structure and therefore has a third dimension, e.g., an anterior/posterior section through the body (cross-section).

The **sagittal plane**, separates the body vertically into right and left portions. Such a section in the middle (median) is called a midsagittal plane, while one alongside the midline is a parasagittal plane. A cross-section, or horizontal section, divides the body into “superior” and “inferior” portions (**Figure 8c**).

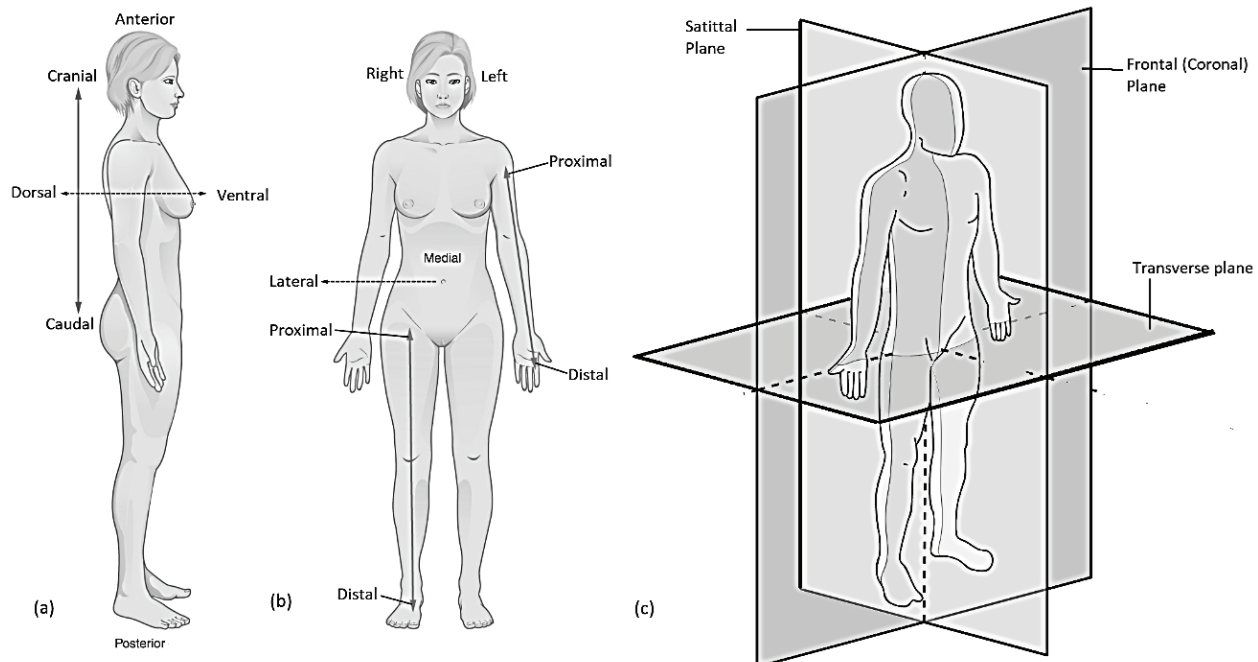


Figure 8: Planes through human body

Table 1: Summary of terms related to positions and planes

Term	Description
Anterior	Closer to front
Posterior	Closer to back
Superior	Located above
Inferior	Located below
Medial	Toward the middle
Lateral	Toward the side
Median	In the midline
Superficial	Near the skin or body surface
Deep	Away from the skin or body surface
Sagittal	Separates the body — vertically
Parasagittal	Separates the body — vertically but parallel to the midline
Horizontal	Separates the body into Cross upper (superior) and lower (inferior) portions
Coronal	Separates the body into —anterior and posterior portions

The **transverse plane** is a plane at right angles to the long axis of a structure or the sagittal plane. The **coronal (frontal) plane** is the plane that separates the “anterior” portion of the body from the “posterior” portion. Coronal refers to a crown-like structure, and a coronal plane divides the body in the same manner as the coronal suture of the skull.

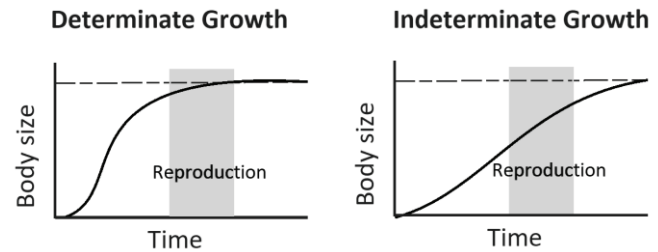
1.3 GROWTH

Growth means increase in size of tissue or organism. It occurs due to cell division and cell expansion. During development, the repeated mitotic division results into large multicellular body starting from a single celled zygote. In plant, cell expansion occurs immediately after the first divisions of the fertilized egg. However, in animals, cell expansion begins slowly. During early stages of animal embryo, only cell division occurs. G_1 and G_2 stages of cell cycle are **absent** and **nucleo-cytoplasmic** ratio increases. The animal embryo may need thousands of cells to become larger than the original fertilized egg.

In early cleavage division embryo shows **isometric growth** where expansion in length is **1.26-fold** when its weight doubles. During isometric growth all the body parts grow at approximately the same rate and it leads to radial symmetry but we know sooner or later this mode of growth would be lost as different morphogenetic events are desired. **Allometric growth** may cause dramatically structural changes in the organisms. Allometric growth leads to unequal growth rate in different parts of the body in comparison to the growth rate of the body as a whole.

The growth strategy of a species influences many key aspects of its life-history. Animals can either grow indeterminately (throughout life), or grow determinately, ceasing at maturity.

During **determinate growth**, growth ceases around/slowly considerably after sexual maturity as observed in most of animals. **Indeterminate growth**, involves continued growth through life. Growth reaches a more or less stable end in some species but continues throughout the individual's life in others (**Figure 9**).

**Figure 9:** Determinate and Indeterminate growth

1.4 DIFFERENTIATION

Embryonic differentiation is the process of development during which embryonic cells specialize and diverse tissue structures arise. Animals are made up of many different cell types, each with specific functions in the body. There are around 210 different types of human cells, e.g., nerve cells, muscle cells, skin cells, blood cells, etc and surprisingly all have its origin from single celled zygote. What makes one cell type different from the other cell types? After all, each cell in the body has exactly the same genome (the entire DNA sequence). How do different cells grow to look so different and to perform such different functions? And how do they get to be that way, out of homogenous (single cell type) early embryonic cells that are produced by cell division of the zygote (the fertilized egg)?

The difference between cell types is in the **differential pattern of gene expression**, i.e., which genes are turned on and which genes are turned off (**Figure 10**).

Genes that code for enzymes involved in neurotransmitter production and reception are transcribed in nerve cells, but there is no need for them to be expressed in muscle cells or epithelial cells. Genes that code for cytoskeletal proteins - keratin that are involved in providing rigidity and strength to cell need not be transcribed hair, nails and epithelial cells and will not be expressed in neuron cells. The patterns of gene expression are specific to cell types and are directly responsible for the differences between morphologies and functions of different cells. Differential gene expression results in production of different types of protein which act as enzymes, structural components, transporter, receptors and many more and leads to differentiation. Regulation of transcription, posttranscriptional event, and translation can leads to differential gene expression.