Module 1

Key Terms and Concepts in Animal Embryology

This module focuses on the terms and concepts every student of embryology must know and understand. These terms and concepts are the basis of how a single fertilized egg cell (called a zygote) becomes a multicellular organism. Make sure you are familiar with these words and concepts since they will be used throughout this course.

Learning Objectives: At the end of this lesson, the student should be able to:

1. Define the terms commonly used in animal embryology.
2. Explain and discuss the concepts in animal embryology.
3. Analyse embryonic events based on the defined terms.

Basic Terms and Concepts in Animal Embryology:

1. Development

Development is the process by which a complex multicellular organism arises from a single cell. It involves an increase in cell number, differentiation, pattern formation and morphogenesis, as well as net growth. Development is a gradual process, so the complexity of the embryo increases progressively. Also, these underlined words overlap with each other as the embryo becomes a functional organism.

The underlined words are the basis of how a single fertilized egg cell, called the **zygote,** and becomes a multicellular organism. We will be looking at these terms one by one later on.

Part of the discussion on the concept of animal development (or for this course, embryology) are:

a. Preformation- An early theory suggesting that the early embryo consists of a miniature version of the adult within the sperm cell and was merely nourished by the ovum (believers are called **spermists**); while the **ovists** argued that the ovum contained a minute body, which was stimulated to grow by the seminal fluid.

b. **Epigenesis** - This concept laid to rest the preformation theory through a series of experiments by *Lazzaro Spallanzani* wherein he demonstrated that in normal circumstances both male and female sex products are necessary for the initiation of development. It was *Kaspar Friedrich Wolff* who conceptualized the word epigenesis, stating that embryonic development occurs through progressive remodelling and growth. This concept basically highlights the role of genetics in the development of animals.

2. Overview of animal development

Although animals show great diversity, the development of most animals proceeds through a number of common stages. These include fertilization, cleavage to form a group of blastomeres, gastrulation to reorganize the structure of the embryo and generate the three germ layers (ectoderm, endoderm and mesoderm), neurulation (formation of the nervous system) and organogenesis (the development of individual organs).

These underlined words are also the topics we will tackle later on.

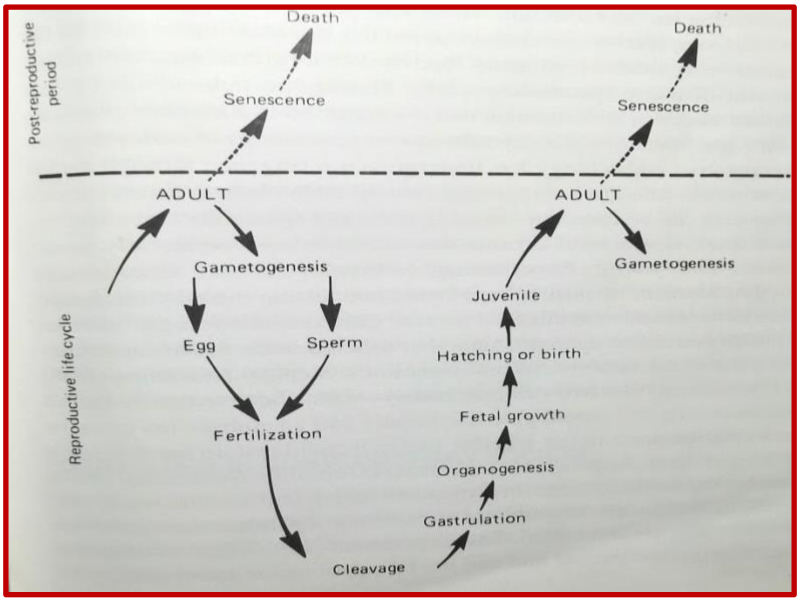
3. Embryology

Embryology is the study of the embryo, which is the earliest stage in animal development. Almost all higher animals start their lives from a single cell, the fertilized ovum (*zygote*). The zygote has a dual origin from two *gametes* – a spermatozoon from the male parent and an ovum from the female parent. The time of fertilization represents the starting point in the life history, or *ontogeny*, of the individual. Ontogeny is an individual's life history – entire life span. Another kind of development in Biology is *phylogeny*, that explains the origin of species (this, however, will not be covered in this course).

Embryology, therefore, is regarded as the period starting with fertilization that ends with: Metamorphosis ⟶ Amphibia

Hatching ⟶ Reptiles and Birds

Birth ⟶ Mammals



The diagram on the left was taken from Carlson (1996) to illustrate the major phases of the life cycle of a typical vertebrate, including humans. Continuity of the germ plasm (in the nuclei of gametes) is indicated by the solid arrows.

This diagram also shows us that at the post-reproductive period, no gametes are produced and this period includes the stage of senescence or aging until death.

Why do you think that the gametogenesis depicted on the right side of the diagram "ends" at that point?

4. Cell division and growth

Although development involves both cell division and growth, these processes can occur independently. During the *cleavage divisions that occur in early animal development, there is an increase in cell number without growth*, so that the egg is divided into a series of progressively smaller cells. Later in development, cell division and growth occur together, although growth may occur without cell division through changes in cell size and the deposition of materials such as bone into the extracellular matrix.

a. Cell division (of the cell cycle) has been covered in the first half which can either be mitosis or meiosis. The formation of an individual as mentioned earlier begins with the fusion of the gametes sperm and ovum. To come up with several numbers of sperm cells and egg cells, mitosis and meiosis are essential.

b. Growth can be defined in many ways. One is simply an increase mass, (most of the time, an increase in mass involves an increase in the number of cellular components). However, all parts of the embryo do not grow at the same time (*differential growth*). An example of differential growth in embryos would be the striking feature of a rapid growth of the head region. During the embryo to the fetal stage, the head is relatively large. Later on, the growth of the body catches up, and the adult proportions are established through differential growth of more caudal regions of the body and limbs.

There are two major patterns of growth in animals

- *Determinate growth* – the body grows to a certain point characteristic of the species and sex, and the growth ceases.
- *Indeterminate growth* – more common in ancestral vertebrates , such as the fishes, in which growth continues throughout the life span, but at a reduced rate in later life.

5. **Differentiation**

It is the process by which different cell types are generated. Cells become structurally and functionally specialized by synthesizing different proteins.

Differentiation thus reflects the activation and maintenance of different patterns of gene expression. It is the actual morphological or functional expression of the portion of the genome that remains available to a particular cell or groups of cells. It is also the process by which a cell becomes specialized, and the final product is called a **differentiated cell.**

Your knowledge of *genetics* covered in the first half is of utmost importance in understanding this process. Take note of these terms: *genes, histones, chromosomal DNA, chromatin, heterochromatin (densely staining chromatin reflecting inactive or repressed genetic material), lightly staining chromatin/genes (derepressed or active genetic material), gene activation, signal transduction.*

(a) Differentiation of cells can be viewed in terms of their biochemistry, their functions and by their morphological appearances:

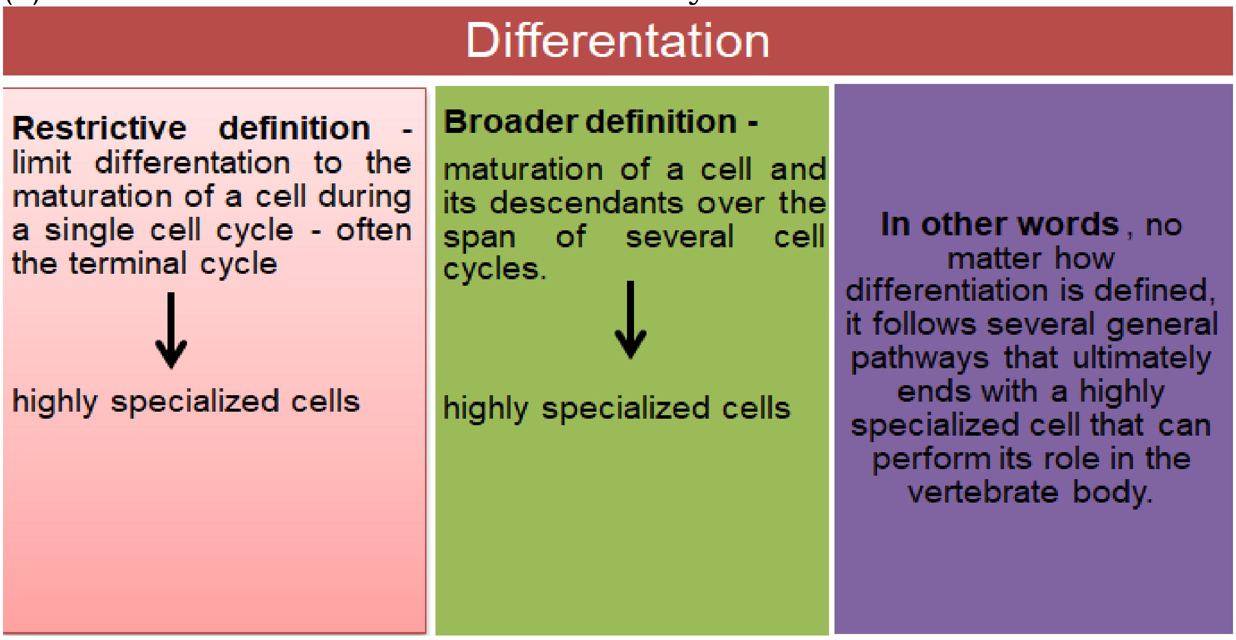
Biochemical(B)	Functional (F)	Morphological (M)
• process by which a cell choose one or few specialized sysnthetic pathways • Example: synthesis of hemoglobin by erythrocytes; synthesis of specific crystalline proteins by the lens	• differentiation of a muslce cell by developing the ability to contract (contractility) • differentiation of a nerve cell to develop conductivity (ability to conduct nerve impulses)	• a skeletal muscle differentiates into elongated like a thread-like cell/fiber with several nuclei • a neuron differentiates into a stellate shape of cells with 2 sets of processess, the axon and the dendrites

Discussion link 1.1: *Give at most 2 examples that would show differentiation in vertebrate embryology from a biochemical, functional and morphological point of view (there are about 250 types of cells in the vertebrate body; each group should have their own examples). For an easy way: the two cells you would think of will show the 3 views of their differentiation. Do not use anymore that are mentioned in the table.*

Example: ***erythrocyte*** *– (B) Haemoglobin synthesis*
(F) Transport oxygen and other materials

(M) Biconcave and with no nucleus

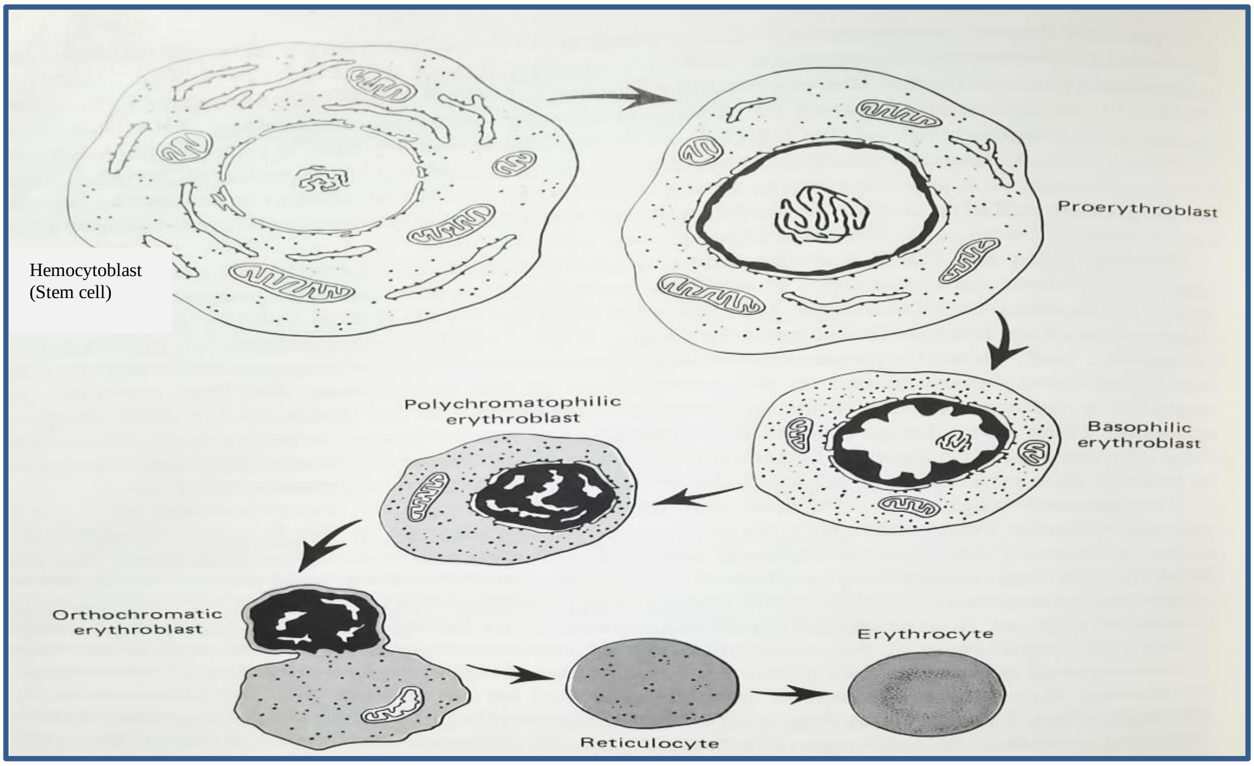
(b) Definitions of differentiation can also vary



A simple example to show the restrictive definition of differentiation would be the differentiation of a stem cell to become a mature functional erythrocyte:

Primitive hemocytoblastic stem cells ⟶ Erythrocytes

A simple example to show the *broader definition* of differentiation would be the differentiation of a stem cell to become a mature functional erythrocyte showing the different stages of development:



It is not important to learn about the formation of mature red blood cells at this point.

Cell differentiation is an expression of changes in the activity of specific genes, which in turn is influenced by a variety of factors inside and outside the cell. The very reason why each cells of the vertebrate body have distinct biochemistry, behaviour/function and structure/morphology is because of **differential gene expression.** Through this process, an embryo can develop into an organism of more than 200 types of cells, each specialized to perform specific functions.

Discussion link 1.2. *What are stem cells? Differentiate totipotent stem cells from pluripotent stem cells? What makes them capable to give rise to various cell types?*

A generalized comparison of an undifferentiated cell from a differentiated cell is shown in Table1-1 as copied from Carlson, 1996. These characters can be applied to both restrictive and broader definition of differentiation.

Table 1-1. Morphological characteristic of undifferentiated versus differentiated cells (Lifted from Carlson, 1996).

Characteristic	Undifferentiated cells	Differentiated cells
Nuclear size	Larger	Smaller
Nucleocytoplasmic ratio	High	Low
Nuclear chromatin	Dispersed	Condensed
Nucleolus	Prominent	Less prominent
Cytoplasmic staining	Basophilic (bluish)	Acidophilic (reddish)
Ribosomes	Numerous	Less numerous
RNA synthesis	Greater	Lesser
Mitotic activity	Great	Reduced
Metabolism	Generalized	Specialized

In your laboratory sessions that require you to view several photomicrographs of various vertebrate embryos in different stages of development, try to apply the information in this table to the cells you are viewing. Determine whether the cells are in the undifferentiated state or in the differentiated state already.

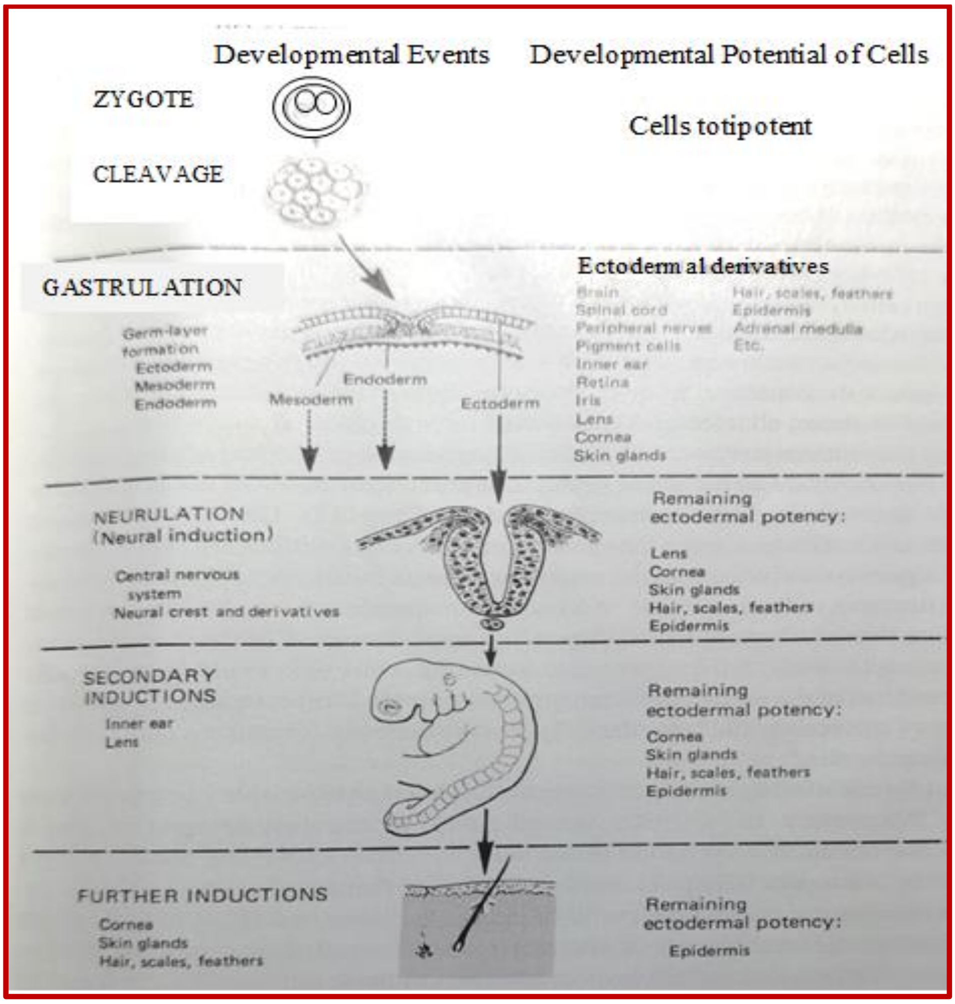
At the tissue level, differentiation can often be recognized as characteristic morphological changes occurring in groups of cells in certain locations and at certain times. The process by which individual tissues take on characteristic appearance through differentiation of their component cells is called ***histiogenesis.*** As you will encounter next time in the topic of organogenesis, most of the discussion in the formation of the organs always involve histiogenesis. As you view the slides of the different stages of embryonic development (beyond gastrulation and neurulation) are entirely about histiogenesis.

The proliferation of cartilage cells to become bone cells later on of bones (duh ☺) will depict for one histiogenesis of the bone tissue.

6. **Determination**

Cell differentiates through **cell determination**, which is a series of molecular events in which the activities of certain genes are altered in ways to that cause a cell to progressively commit to a particular differentiation pathway, ***making it a specialized cell.*** As cell determination proceeds, it **restricts** an embryonic cell's developmental pathway so that its **fate** becomes more and more limited. Once a cell has differentiated into its characteristic appearance and activities, it is **irreversibly committed** to its fate. (Lifted from Solomon et al, 2008)

The diagram below is taken from Carlson (1996) illustrating restriction during embryonic development. The column on the right shows the progressive restriction of the developmental capacity of cells along one track, that eventually leads to the formation of the epidermis, and is irreversibly committed to be cells of just the epidermis, and nothing else. The column on the left, on the other hand, describes the major developmental events that remove groups of cells from the epidermal track. These events will be tackled in the succeeding meetings.



7. Nuclear equivalence.

You might wonder, how can a single fertilized egg cell give rise to a multicellular organism with more than 200 types of cells, specialized to perform specific functions? If those 200 or so differentiated cells make unique sets of protein, early scientists hypothesized that each group of cells loses the genes it does not need and retains only those required. But this is not generally true.

According to the theory of **nuclear equivalence**, the nuclei of essentially all differentiated adult cells of an individual are genetically (but not necessarily metabolically) identical to one another and to the nucleus of the zygote from which they descended. In other words, all **somatic** cells in an adult have the same set of genes, but the cells express different subsets of genes as what was mentioned earlier in the topic of cell differentiation – which is what we call **differential gene expression.** Nuclear equivalence is the principle that underlies the cloning of organisms.

Discussion link 1.3. *Briefly, in not more than five sentences, explain why the understanding of gene regulation is important to the understanding of developmental processes?*

8. **Morphogenesis and Pattern formation.**

Cell differentiation does not explain development nor is the end of development. Once the cells have differentiated to what they are *fated* to become and *restricted* in their respective *forms and functions*, these cells must become progressively organized, through shaping of the intricate pattern of tissues to become organs characteristic of a multicellular animal. The development of form is called **morphogenesis,** and proceeds through the process of **pattern formation**.

Pattern formation is a series of steps requiring signalling between cells, changes in shapes of certain cells, precise cell migrations, interactions with the extracellular matrix, and even **apoptosis** (programmed cell death of some cells to achieve the final form of the tissues and the organs of the adult vertebrate.

In many systems, pattern formation (laying down of the morphogenetic blueprint) is distinguished from morphogenesis (realization of the plan). So in the construction of your dream house, what part is the pattern formation, and which part is the morphogenesis?

Discussion link 1.4. *Explain in your own words morphogenesis using the following words (not in the given order) in your 1 paragraph answer. Make sure to underline these words in the paragraph for checking purposes.* ***body parts, being, development, growing, growth, maturation, ontogenesis, organism***

To end this module, these concepts given here are just few of the many things you have to know in the basic understanding of animal embryology. The other words and concepts that you should be familiar with will be mentioned in the succeeding topics as they are discussed further.

BOOK REFERENCES:

1. Carlson, B.M. 1996. Patten's Foundation of Embryology. 6th ed. McGraw Hill Book Company.
2. Solomon EP, Berg LR and Martin DW. 2008. Biology. 8th ed. Thomson Brooks/Cole.
3. Tywman, R.M. 2001. Instant Notes Developmental Biology. Springer.
4. Wilt, F & S. Hake. 2004. Principles of Developmental Biology. W.W. Norton & Company.