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INTRODUCTION TO PRINCIPLES OF ZOOLOGY II LABORATORY

INTRODUCTION TO LABORATORY PROCEDURES

1. Be on time and plan to study laboratory material for the entire laboratory period (110 minutes).
   a. At the beginning of lab, the instructor will provide a brief summary of important material you should cover during each lab period.

2. Read appropriate lab-manual chapter and scientific article prior to attending lab (see schedule below).
   a. You are responsible for finding and printing out assigned scientific articles to read and bring with you for use during laboratory periods (see Literature Cited list below).
   b. Appendix IV provides helpful instructions for finding literature via the WSU Stewart Library.

3. Peruse relevant chapters of your textbook (Integrated Principles of Zoology, 15th edition) prior to attending lab (see schedule below) to find relevant information and familiarize yourself with animals you will be studying.
   a. Bring your textbook with you to lab because visual aids and associated information will be useful as you study laboratory material.

4. Bring Henderson’s Dictionary of Biology with you to lab.
   a. You will need this resource to clarify terminology you encounter during lab.

5. Microscope slides you will use during the entire semester are organized into slide boxes. Each box has the full complement of slides for the entire semester.
   a. During a given lab period, take a slide box and compound microscope back to your desk and select the slides from the box that are relevant to the subject being covered that period. Be sure to be able to recognize all important features (bold words) as well as the taxonomic groups represented (based on groups featured in the lab manual and in lecture).
   b. Keep slides organized properly within the box you collect them from.

6. Specimens you use will be available in the laboratory during your lab period. Take careful notes on lab specimens because you may not have a chance to view them again prior to quizzes and exams.

7. Focus on recognizing characteristic features of all taxonomic groups we study (i.e., phyla, subphyla, class, order, etc.)
   a. You must be familiar with the names of all taxonomic groups emphasized in the lab manual including proper spelling and capitalization (capitalize proper nouns such as formal scientific names)
   b. Direct questions to your lab instructor if you have gone through the reference material and are unclear about the membership of each group or characteristic features.
   c. You should be able to use characteristic traits to identify specimens as members of taxa they represent.

8. Be familiar with bold words so that you understand their importance and, if they refer to anatomical features, make sure you can recognize the features on representative specimens.
   a. Bold words are your study guide for the portion of lab exams that covers laboratory materials and important concepts.
   b. For quizzes and exams, you will be responsible for proper spelling
   c. Direct questions to your lab instructor if you cannot understand the importance of bold words or locate anatomical features on your specimens.

9. Keep detailed laboratory notes to facilitate study for quizzes and exams.


LABORATORY GRADE

Your performance on lab quizzes, reports, and exams will determine one third of your total course grade (200 points). You cannot earn a “C” or better unless you earn some laboratory points. You will need to perform well in lab and lecture to earn a “B” or higher. Your laboratory grade will be based on your performance on:

1. **Lab quizzes** – (10 quizzes, 10 points each, 100 points total) will facilitate your review of each lab immediately previous and prepare you for the next, upcoming lab. Quizzes will include primarily fill-in-the-blank, matching, true-false and multiple choice questions.
   a. “Quizzable” material includes:
      i. Information from the previous week including material from your lab manual, textbook, assigned scientific articles, and material viewed during lab.
      ii. Information from the lab manual for the upcoming lab.
   b. *Proper spelling and capitalization are required.*
   c. **Lab quizzes:**
      i. Your instructor will make available a schedule for lab quizzes
      ii. **Quizzes must be taken during the period indicated except in the case of verifiable emergency or prior arrangement. There are no exceptions.**

2. **Lab report** – (1 report, 50 points total) this assignment will familiarize you with rules for effective scientific reporting. You will collect data for your lab reports during lab. You must be present or have an excused absence (prior arrangement or verifiable emergency) to collect and use the data. Detailed instructions are provided in this lab manual. The grading rubric to be used by the instructor is provided at the end of the lab manual. You are responsible for understanding all instructions and rubric items prior to turning in your lab report.
   a. Use “Henderson’s Dictionary of Biology” (required text) and the book “Scientific English” (recommended text) as guides for appropriate writing style and grammar.

3. **Lab practical exam** – (1 exam, 50 points total) this activity will test your knowledge of lab topics. Fill-in-the-blank test questions will test your knowledge of important anatomical characteristics. Question format for the lab exam will be consistent with that for quizzes, but the lab exam will be specimen based, meaning you will be viewing actual specimens from lab and be required to identify taxa they belong to, representative traits of those taxa, and anatomical features emphasized during labs.
   a. **Fill-in-the-blank questions** will refer specifically to bold words or taxonomic groups emphasized in lab. You must be able to tell the different animal taxa apart.
   b. *Points will be deducted for improper spelling or capitalization.*
INTRODUCTION TO TAXONOMIC LEVELS
Biologists attempt to organize all living things into a series of hierarchical taxonomic levels that correspond to hypothesized levels of relatedness among taxa. The most inclusive taxonomic level is the Kingdom. In the Department of Zoology (and thus in this course) we study the animal Kingdom (Kingdom Animalia). Other major taxonomic levels, in order from more to less inclusive, are the Phylum, Class, Order, Family, Genus, and Species. However, as you will see, there are also many intermediate groups including the sub-phylum, super-class, and sub-species. A major emphasis in Principles of Zoology II is to introduce you to the diversity of animals by introducing you to selected taxonomic groups.

Labs will introduce you to the best-known animal phyla and, in some cases, to well-known taxa of lower hierarchical levels (e.g., sub-phylum and class). You will focus on anatomical characters such as body complexity (level of body organization), body symmetry, embryonic development (number of germ layers, body cavity type), and reproductive biology because they have high evolutionary significance.

Taxa assigned to a given phylum (or any other taxonomic level) share anatomical traits that are absent or present in different combinations in other phyla. As a result, animals grouped into the same phylum are hypothesized to be more closely related to each other than to any other animals because they are all descendants from a common ancestor. Anatomy, physiology, and life history differ dramatically among members of different phyla so animals from different phyla are relatively easy to tell apart once you become familiar with their identifying characteristics (this is a goal in Principles of Zoology II). Note that a similar approach based on the concepts of common descent is used to group taxa into each taxonomic level. Animals that comprise more specific taxonomic levels are more anatomically similar and presumably more closely related, having shared a more recent common ancestor. Throughout the semester, pay careful attention to traits that distinguish members of different taxa from each other.
CHAPTER 1: HOMOLOGOUS TRAITS, DIVERGENCE, & PHYLOGENY

Study of homology is the foundation for traditional taxonomic study and is commonly used as a basis for constructing animal phylogenies. Homologous traits are those that have a common origin (i.e., they were inherited from a common ancestor and have similar embryological origins and development). Thus, members of monophyletic groups (i.e., groups of organisms including an ancestor and all its descendants, also called clades) typically share a suite of homologous traits that is unique to the group.

A homologous trait is often called a homolog (also spelled homologue). Evolution of homologues to serve different functions can result in divergence. In this case, taxa with homologues similar to the common ancestor are considered ancestral members of a clade, whereas taxa with a homologue much different from the common ancestor are considered derived. Derived versions of a homologue can be characterized by their apomorphies, which are novel modifications of an ancestral trait. In a “perfect” phylogeny, the phylogenetic tree (called a cladogram) is labeled at each branching point (called a node, Fig. 1.1) and taxa “above” each node on the tree all share the same apomorphy. Shared apomorphies are called synapomorphies. Synapomorphies represent homologues for higher-level clades (i.e., subgroups) within a cladogram. Synapomorphies present at a node that is low (nearer to the base) of a cladogram are ancestral and include more members of the clade than derived synapomorphies, which are higher (nearer to the leaves) of a cladogram. The root of the cladogram represents the common ancestor of the clade and branches represent divergent lineages. Branches “higher” on the tree are hypothesized to represent more recent divergence. Leaves at the ends of branches represent taxa that are members of the clade.

In this lab, you will construct a cladogram using members of phylum Chordata (a monophyletic group). To construct your cladogram:

1. Work in groups of 3 or 4.
2. Determine which taxon is most ancestral (Fig. 1.1).
3. Determine the taxonomic hierarchy of each trait, from ancestral to derived.
4. Based on the combination of traits, determine a phylogenetic tree (e.g., Fig. 1.1), including specification of apomorphies present at each node (more than one can be present).
   a. Do not concern yourself with “official” names for apomorphies you identify, just create your own descriptive names.
5. Refer to your textbook and lab manual as needed.
6. Discuss your findings with other groups.
7. Wait to discuss your findings with the entire class (led by your lab instructor).
Figure 1.1. Two versions of the same cladogram showing nodes and branches. All taxa above node a (including taxa A, B, and C) share one or more apomorphies that distinguish them from the root taxon. Similarly, all taxa above node b (taxa C and B) share one or more apomorphies that distinguish them from taxon A.
To begin, look up the following terms in your textbook (Hickman et al. 2011) and in Henderson’s Dictionary of Biology (Lawrence 2008):

1. *Taxon*

2. *Axial skeleton*

3. *Notochord*

4. *Cervical vertebrae*

5. *Thoracic (trunk) vertebrae*

6. *Lumbar vertebrae*

7. *Sacral vertebrae*

8. *Caudal vertebrae*

9. *Pelvic girdle*

10. *Pectoral girdle*

11. *Tetrapod*

12. *Cranium*

13. *Mandible*

14. *Fenestra*
The following homologous traits will be the basis of your phylogenetic classification:

1. **Axial skeleton homologues** – derived axial skeletons are more complex, including more different “types” of vertebrae and more vertebrae fused together.

2. **Girdle-limb homologues** – derived girdles and limbs articulate more directly with the axial skeleton and have more complex and robust limbs with fused bones. Alternative derivations include derived positions of girdles vis-à-vis the articular skeleton.

3. **Skull homologues** – in ancestral skulls, the cranium is encased within an outer skull wall formed by fused bones. In derived skulls, arches span openings (fenestra) that have developed in the outer skull wall. Fenestra may also be present in the lower jaw (mandible). In even more derived skulls, the arches, and thus the outer skull wall, are lost altogether, leaving the cranium fully exposed.

4. **Mouth-jaw homologues** – derived mouths have jaws. Derived jaws may have increased mobility due to incorporation of more bones and more joints where bones articulate, derived teeth, or beaks in place of teeth. Derived lower jaws (mandibles) may include fenestrations.

The following taxa will be members of your Chordate cladogram:

1. Amphioxus (w. m. microscope slide)
2. Yellow perch skeleton
3. Alligator skeleton
4. Ibis skeleton
5. Pigeon skeleton
6. Snapping turtle skeleton
7. Water turtle skeleton
CHAPTER 2: ANCESTRAL DEUTEROSTOMES

All multicellular organisms—fungi, plants, and animals—acquire cell specialization during development. **Triploblastic, coelomate** animals are classified as **protostomes** or **deuterostomes** based on certain details of their embryonic development. Fundamental differences between protostomes and deuterostomes mark an important evolutionary split that occurred at least 600 million years ago. Annelids, molluscs, and arthropods (for example) are protostomes. In contrast, phyla covered in today’s lab—Echinodermata and Chordata—are deuterostomes. Deuterostome embryonic cells exhibit **radial cleavage** and **indeterminate development**. The body cavity that holds major organs (the **coelom**) forms by the out-pocketing of mesoderm (**enterocoely**) and the **blastopore** develops into the anus. Animals may have: (1) **indirect development**, defined by having at least one larval stage morphologically distinct from adults or (2) **direct development**, defined by absence of a morphologically distinct, free-living larval stage. In direct development, larvae are brooded or encapsulated by the parent until they are born or hatch as juveniles (immature, but otherwise similar to adults). Events of early development are similar among deuterostomes. Given that echinoderms are a good model, exhibits in this lab will be used to introduce you to the major embryonic stages.

**PHYLUM ECHINODERMATA AND ANIMAL DEVELOPMENT**

Phylum Echinodermata includes a variety of unique animals with a suite of anatomical features much different from those observed in any other phylum. The group is also ancient and includes substantial variety. The phylum includes sessile filter feeders, mobile scavengers, grazers, and predators. However, echinoderms occupy only marine and coastal habitats. All echinoderms share the following homologous traits: a **water-vascular system**, **pentaradial symmetry**, **dermal endoskeleton**, **pedicellariae**, and **papulae** (dermal branchiae, skin gills).

**Exhibits for Animal Development and Phylum Echinodermata**

1. **Starfish development** (w. m. slides; for future reference, c. s. = cross-section; l. s. = longitudinal section; and w. m. = whole mount): observe developmental stages between the **zygote** and **bipinnaria** of sea stars. Identify the following objects on the microscope slides: **blastula**, **blastopore**, **blastomere**, **blastocoel**, **cleavage**, **archenteron**, **gastrula**, **gastrulation**, and **zygote**. Cleavages (cell divisions) that occur during early development produce more and more smaller and smaller cells (i.e. cell number increases but the size of the organism does not). Note the importance of gastrulation and its connection to development of the three embryonic germ layers—**ectoderm**, **mesoderm**, and **endoderm**—and to the body axis and form of the developing animal. Echinoderms have indirect development. For example, adults have **pentaradial symmetry** but larvae have **bilateral symmetry**. Hence, larvae undergo a dramatic metamorphosis to become juveniles. The bilateral larvae also indicate echinoderms had a bilaterally symmetric ancestor.

2. **Sea star dissection**: Identify the **oral** and **aboral** sides, **tube feet**, **ambulacral groove**, **ampullae**, **skin gills** (dermal branchiae), **spines**, **pedicellariae**, ** madreporite**, **mouth**, **ossicles** (of **endoskeleton**), **stomachs**, **stone canal**, **ring canal** and **radial canals**. Surface features are best viewed under a dissecting microscope. The **dermal endoskeleton** and **water vascular system** (a derivative of the **coelom** used for feeding and locomotion) are unique to the phylum.

3. **Miscellaneous echinoderm specimens**: Identify the five living classes of echinoderms: **Crinoidea**, **Asteroidea**, **Ophiuroidea**, **Echinoidea**, and **Holothuroidea**. Look for representatives of each group among the specimens provided and in the saltwater aquarium at the back of the classroom.
PHYLUM CHORDATA
All chordates share five “chordate hallmarks” present at some stage of development: (1) **dorsal, hollow nerve cord**, (2) **cartilaginous notochord**, (3) **pharyngeal pouches (arches and slits)**, (4) **post-anal tail**, (5) **endostyle (thyroid)**. Identify each hallmark and understand its structure and purpose. Chordates may have indirect or direct development and occupy a wide variety of aquatic and terrestrial habitats. Most chordates are in **subphylum Craniata**, but there are also two subphyla of invertebrate chordates: (1) **Urochordata (tunicates)** and (2) **Cephalochordata (lancelets)**. Like echinoderms, invertebrate chordates are exclusively marine. Most are filter feeders.

EXHIBITS FOR ANIMAL DEVELOPMENT AND PHYLUM CHORDATA
1. Sub-phylum **Urochordata**: preserved tunicate specimens. Most tunicates are sessile, filter feeders. They have “tadpole-like” larvae that exhibit all chordate hallmarks. Free-swimming larvae eventually attach to a suitable substrate and transform into sessile, filter-feeding adults. What chordate hallmarks do adult tunicates retain? Which are lost? The common name “tunicate” derives from the cellulose **tunic** (body covering) present in many species.

2. Sub-phylum **Cephalochordata**: *Branchiostoma* sp. (preserved specimens and w. m. slide). These invertebrate chordates are typically only a few centimeters long. They can swim, but spend most of their time partially buried, where they filter feed. Lancelets pre-date vertebrates. Fossils as old as 550 million years are known. The name “lancelet” refers to a “little scalpel” for the sharp, two-edged appearance of cephalochordates. Examine the lancelet slide and specimens and identify as many chordate hallmarks as possible along with the **dorsal and caudal fins, mouth, pharynx, intestine, anus, and atripore**.

3. Sub-phylum **Craniata**: Hagfish, class *Myxini*, and lamprey, class *Petromyzontida*, (preserved specimens and w.m. slide). These specimens represent the two living lineages of jawless craniates, referred to as “agnathans”. The two lineages are distinct from each other and are basal within the subphylum. Hagfish have a simple cranium and “incipient” cartilaginous vertebrae (vertebral homologues not considered true vertebrae). Lampreys have a cranium and rudimentary, cartilaginous vertebrae.

4. Sub-phylum **Craniata**: Zebrafish and chicken larvae (w. m. slides). Compare slides of a larval zebrafish and chicken with those of *Branchiostoma* and a larval lamprey (ammocoete). Can you see any chordate hallmarks? What other similarities are there?
CHAPTER 3: SKELETAL DIVERGENCE AMONG AMNIOTES

An amniotic egg, relatively thick skin, lung aspiration breathing, strong jaws, high-pressure cardiovascular system, water-conserving nitrogen excretion, and an enlarged central nervous system with complex sensory organs characterize all members of the group Amniota. This highly successful group has undergone much diversification of these and associated traits. To us, various amniote lineages appear very different, but in truth they possess homologous body plans, including features common among chordates, craniates, and tetrapods (all groups to which amniotes belong). However, each amniote lineage also has characteristic traits (synapomorphies) consistent within each, but different from members of other lineages. Your goal in this laboratory will be to detect both similarities that belie ancestral relations (homologies) as well as differences that distinguish major amniote lineages (Synapsida versus Diapsida) and subdivision of Diapsida (Lepidosauria, Testudines, and Archosauria). Observe the various articulated skeletons and use accompanying visual aids and your textbook to identify major components of amniote skeletons.

Look up the following anatomical terms in “Henderson’s Dictionary of Biology” or your textbook (avoid vague or imprecise terms such as “up” or “down”):

- **Anterior:**
- **Appendicular:**
- **Articulate (articulation):**
- **Axial:**
- **Caudal:**
- **Cranial:**
- **Distal:**
- **Dorsal:**
- **Lateral:**
- **Medial:**
- **Posterior:**
- **Proximal:**
- **Rostral:**
- **Ventral:**

**SYNAPSIDA (living mammals and their direct ancestors)**

Begin your study of amniote diversity by familiarizing yourself with the skeletons of synapsids. You are a synapsid, so the skeletal features should be familiar to you already. How does your skeleton compare to that of other synapsids? How much divergence among synapsids can you detect?

1. **Axial Skeleton** - The axial skeleton consists of the skull, vertebral column and ribs. Mammals (and their ancestors, the synapsid reptiles) have synapsid type skulls, with a single bony (zygomatic) arch and one temporal fenestration through which a jaw muscle (the temporalis) passes. The vertebrae (bony segments of the vertebral column) are differentiated into 5 regions, listed here from cranial to caudal: cervical vertebrae, thoracic vertebrae, lumbar vertebrae, sacral vertebrae, and caudal
vertebrae. Mammals typically have 7 cervical vertebrae. The two most cranial vertebrae (the atlas and axis, respectively) allow up-and-down movement and rotation of the head. The remaining five cervical vertebrae are unnamed, but lack ribs and have characteristic transverse processes and foramina (singular = foramen). How can you distinguish vertebrae of other regions? Numbers of vertebrae and ribs in other regions vary with species, but the skeleton of a housecat (Felis catus) provides an example:
  • Housecat = 13 thoracic vertebrae, all with a prominent dorsal spine. Thirteen ribs articulate with the thoracic vertebrae dorsally and sternum ventrally. Costal cartilages connect the bony ribs and sternum.
  • Housecat = 7 lumbar vertebrae with transverse processes representing fused ribs.
  • Housecat sacrum = fused sacral vertebrae. The pelvis articulates with the sacrum.
  • Housecat caudal vertebrae compose the tail and are relatively small. How many are there?

2. Appendicular Skeleton - the appendicular skeleton is comprised of limbs paired with girdles.

Forelimb - The most proximal element of the forelimb is the humerus (upper arm bone). It articulates with the radius and ulna (forearm bones) that articulate with the wrist bones (carpals). Continuing distally are metacarpals (hand bones) and phalanges (finger/digit bones; singular = phalanx). Digits are numbered from medial to lateral, so the “thumb” is digit 1 (pollex).

Pectoral girdle - The forelimb articulates with the scapula, which possesses a prominent lateral spine. The other component of the pectoral (i.e., shoulder) girdle is the clavicle (collarbones), which articulates with the scapula and sternum in humans. Is this consistent among other mammals? Why or why not?

Hind limb - The hind limb has the same pattern of skeletal elements as along the forelimb. The single thigh bone (femur) articulates at the knee with the tibia and fibula (foreleg bones). These articulate with the ankle bones (tarsals). Continuing distally are metatarsals (foot bones) and phalanges. How do digits differ between the forelimb and hind limb of the cat (e.g., which digit is missing from the hind limb)? Compare with other mammals. At the end of the digits are claws (keratinized epidermis) that fit over the last phalanx (ungual) like a sheath. The cat walks on its toes (digitigrade foot posture). How does human foot posture (plantigrade) differ? An “extreme” mammalian posture is unguligrade, as in hoofed mammals. Compare foot posture among mammal specimens.

Pelvic girdle - The pelvic girdle (composed of three fused bones, the ilium, ischium, and pubis) is more solidly connected to the vertebral column than the pectoral girdle, and is less variable among mammal lineages. The ilium (our hip) faces cranially, the ischium caudally (the bone we sit on), and the pubis ventrally. Why would the pelvic girdle be relatively similar among all amniotes (a very diverse group)?

DIAPSIDA (living lizards, snakes, turtles, crocodilians, birds and relatives)
The amniote group Diapsida includes several lineages with very divergent skull and skeletal features. Compare and contrast diapsids in general with synapsids and then compare and contrast diapsid lineages. Why is Diapsida more diverse and divergent than Synapsida (or is it)?

1. Lepidosauria – Lepidosauria includes two major living lineages. The primitive diapsid skull type with two temporal fenestrations and two associated arches is seen only in tuatars, relict reptiles that persist only on islands near New Zealand. Remaining lepidosaurians with modified diapsid skulls (lizards and snakes) are all within the group Squamata. Lizards have lost the lower arch of the skull, and snakes have lost both arches. These losses increase the mobility (kinesis) of the skull. In the kinetic diapsid skull, the quadrato bone is jointed on both ends and the cranial part of the cranium is also flexible. How do other features of lepidosaurian skeletons compare with those of synapsids? Note that snake bodies are highly modified. They lack limbs (though some primitive forms, like pythons, retain vestigial hind-limb girdles) and are very elongate, with hundreds of vertebrae and ribs. Any idea why snakes lack a sternum?
2. **Archosauria** – skulls of true dinosaurs (see replicas), crocodilians, and birds are an *archosaur* type (modified diapsid) that includes one or two additional fenestrations (besides the temporal ones) that may be either *mandibular* or *antorbital*. Observe the replica dinosaur skull and find both temporal fenestrations and arches as well as mandibular and antorbital fenestrations.

   a. **Crocodilia** – crocodiles and alligators possess a modified *diapsid* skull with *mandibular fenestrations*. Note the inflexible (*akinetic*) nature of crocodile skulls. Compare the vertebral, limb, and girdle structure with other types of amniotes.

   b. **Aves** – in birds, temporal fenestrations have enlarged and merged with the orbit. The lower arch is retained, but is long and thin. Note the increase in cervical vertebrae compared to synapsids. Many vertebrae are fused to create a more rigid vertebral column. Note the fused thoracic vertebrae (*notarium*), and lumbar, sacral, & caudal vertebrae fused with the pelvis (*synsacrum*). Remaining caudal vertebrae are few and fused to form the *pygostyle*. What is the benefit of fused vertebrae? The ribs have no costal cartilages, are jointed, and articulate with the massive and *keeled sternum*, which allows for the attachment of flight muscles (*pectoralis* and *supracoracoideus*). The avian wing is highly modified for flight and possesses a *humerus, radius* and *ulna*. The carpals (all but 2) and metacarpals are fused into a rigid *carpometacarpus* and there are only 3 digits. The shoulder girdle is made up of a *coracoid, scapula*, and *furcula*. Note the space (*triosseal foramen*) for passage of the supracoracoideus muscle (which lifts the wing during flight) where these bones articulate. The hind limb consists of a *femur* and *tibiotarsus* (fused tibia, fibula, and tarsals). Distally is the *tarsometatarsus*, a “compound” bone made up of metatarsals and tarsals that articulates with the digits of the foot. Digit 1 of the hind limb (*hallux*) faces backward. Note that bird knees bend “normally” (as in humans). Why do birds appear to have backwards-bending knees?

3. **Testudines** – some turtle skulls lack temporal arches and fenestrations, a condition termed *anapsid*. However, others (such as those you will see in lab) have undergone *skull emargination* (development of fenestrations and arches) that is *analogous*, but not homologous to emargination in other diapsids. Turtles are also distinguished by their shell, made up of a dorsal *carapace* and ventral *plastron*. These elements are made up of ribs and thoracic vertebrae fused to dermal bony elements and covered with keratinized epidermal plates (*scutes*). Observe the limbs and limb girdles located inside of the shell. How does this differ from other amniote limbs and girdles? Note the position of the scapula and locate the *carapacial ridge*.
CHAPTER 4: SKULL DIVERGENCE AMONG SYNAPSIDS

This lab introduces diversity and divergence in synapsid skulls of living mammals with emphasis on teeth. The anatomy of the lower jaw (formed by a single bone, the dentary), presence of diphyodont teeth (“baby” teeth replaced by permanent teeth), and (in most cases) presence of heterodont teeth that vary in structure perform different functions for an organism help distinguish living synapsids (mammals) from diapsids. Heterodont teeth are derived features among synapsids. Examples of ancestral synapsids (i.e., mammal-like reptiles) can be viewed in the WSU Museum of Natural Science on the main (middle) floor of Lind Lecture Hall. The dimetrodon skeleton located in the main (circular) hallway near the elevator provides a particularly nice example. Contrast this skull with others in the museum and those you viewed during the “Skeletal Divergence among Amniotes” lab (Chapter 4).

In this lab, focus on jaw anatomy and musculature and divergence among heterodont teeth of different mammal lineages. Be sure you can answer the questions: (1) What is a dental formula? (2) How is the dental formula determined? (3) How is tooth anatomy and diversity related to diet? Begin by examining the skulls of a canid (either Canis latrans, the coyote or Canis familiaris, the domestic dog) and felid (either Felis concolor, the cougar or Felis catus, the housecat). Use the figures below and in your textbook to get started.

Cranial crests provide points for jaw-muscle attachment. The sagittal crest at the very top of the skull connects to the nuchal crest on the back of the cranium. The temporalis muscle attaches from the sagittal and nuchal crests to the coronoid process of the lower jaw (mandible composed of the dentary). The masseter muscle extends from the zygomatic arch (the cheekbone) to a depression on the lateral surface of the mandible. The final jaw muscle is the pterygoid muscle, extending from the “winglike” processes on the ventral surface of the cranium (“ptery” means “wing”) to the medial surface of the mandible, opposite the masseter. Relative size and arrangement of jaw muscles reflects diet (e.g., meat vs. plants). How would you expect muscles and crests to differ in herbivores? Do the comparative examples in lab fit your expectations?
Teeth are valuable tools for identifying diet, habitat relations, and evolutionary relationships of mammals. Some prehistoric mammals are known only from fossil teeth. Tooth composition includes four layers (listed from outer to inner): enamel composed of 98% mineral (hardest), dentine 70% mineral, cementum 50% mineral, pulp little mineral content (softest). Posterior teeth (molars, premolars) and canines may have multiple cusps (elevations on an occlusal [grinding, biting] surface). Mammals of different lineages display different types of cusps. Carnivores and omnivores commonly have bunodont cusps that are completely covered with enamel. Why would carnivores need hard teeth? Herbivores and granivores, on the other hand, commonly have selenodont or lophodont cusps, in which all tooth layers are exposed. The layers wear at different rates, creating a cutting edge. What would be an advantage of sharp and jagged tooth cups for herbivores? How would this interact with different skull structure and jaw musculature?

Heterodont teeth: There are four main types of mammal teeth:

1. Incisors (I) – little teeth at the front (cranial or rostral) of the skull.
   a. Incisors are diphyodont teeth
   b. The coyote has six upper and six lower incisors
2. Canines (C) – big stabbing teeth
   a. Canines are diphyodont teeth
   b. The coyote has two upper and two lower canines
3. Premolars (P) – tearing or grinding teeth present mid-jaw
   a. Premolars are diphyodont teeth
   b. The coyote has eight upper and eight lower premolars
4. Molars (M) – tearing or grinding teeth at the back of the jaw
   a. Molars are permanent (monophyodont) teeth
   b. The coyote has four upper and six lower molars

Carnassial teeth: perhaps the most impressive teeth in carnivores (including canids and felids) are the large blade-like teeth called carnassial teeth, which are used to slice meat like scissors. In carnivores, carnassial teeth are used to distinguish premolars from molars. The carnassial on the upper jaw represents the 4th (last) premolar. The carnassial on the lower jaw represents the 1st molar. In other synapsids, premolars and molars may be difficult to distinguish and you will not be asked to do so in this course.
The dental formula: The dental formula is a count of each tooth type. The number of teeth on the left and right sides of each jaw is usually the same, but may differ between upper and lower jaws. Hence, the dental formula is a count of only one side of the jaw, but made separately for upper and lower jaws (the total number of teeth is two times the dental formula).

The coyote dental formula = I₃.C₁.P₄.M₂ (number of teeth by type in 1/2 of the upper jaw) 
I₃.C₁.P₄.M₃ (number of teeth by type in 1/2 of the lower jaw)

This is typically abbreviated:  
\[
\begin{align*}
3.1.4.2 \\
3.1.4.3 \\
\end{align*}
\]

By comparison, the primitive mammalian dental formula is:  
\[
\begin{align*}
3.1.4.3 \\
3.1.4.3 \\
\end{align*}
\]

In the process of mammalian evolution, teeth are normally lost, not gained. Compare the canid tooth count to that of a felid. Which has a more ancestral dental formula? Based on appearance, what is the function of the felid molars? Can you explain this difference based on your observations of dogs and cats?

Find an herbivore skull. Can you find and differentiate tooth types? How do you explain the differences you see? Most herbivorous mammals have a space called a diastema, which represents a region where teeth have been lost evolutionarily and/or the jaw has been lengthened. Any ideas why? Some herbivores are also missing upper incisors. How do you explain this?
CHAPTER 5: OWL PELLET ANALYSIS

BACKGROUND
Many kinds of predatory birds swallow their prey whole or in large pieces. Indigestible remains (bones, fur, feathers, chitin, etc.) are compacted into a pellet in the stomach and regurgitated several hours later. This makes it relatively easy to study what predatory birds eat because pellet contents can be identified. In this laboratory, you will dissect pellets of the Barn Owl (*Tyto alba*), a species that eats small craniates. You will then use a dichotomous key to identify prey animals to the genus level.

METHODS
Part one, animal detection and size-frequency analysis: Each student should dissect one pellet. Use the tools provided to pick apart the pellets and separate the bones from the fur. Dissect and clean all bones. Use the figure below (and your knowledge of vertebrate anatomy) to determine how many different individual animals are present. In small mammals, mandible length can be used as a gross measure of individual size. Use a caliper or ruler to measure the length of each mandible representing a different mammal. Enter the number of animals detected and all associated mandible lengths on the chalkboard. Once each student has entered their mandible lengths, use your best reasoning (you can work in groups) to determine whether there is a trend in size preferred by Barn Owls or if there is no size preference and whether there is a relation between the numbers of animals detected per pellet versus their overall size. Would you expect a trend or a relation? Be prepared to participate in group discussion.
Part two, skull identification and introduction to a dichotomous key: identify all skulls you detect, with the dichotomous key (following pages). Dichotomous keys work by providing a series of choices. Each pair of choices is called a couplet. The choice you make at each couplet directs you to the next couplet on the key. When you have made the correct series of choices, you end at the appropriate name for your specimen. Dichotomous keys are common in zoology and often used by naturalists and taxonomists.

If you do not find all of the species on the key in your pellet, study the skulls of other species found by your classmates and use example skulls provided by your instructor to become proficient in identifying them all by becoming familiar with using a dichotomous key and by becoming familiar with distinguishing traits.

When identifying skulls you should be able to recognize different adaptations for diet among the prey types and you should also be able to recognize cusp type (review material from Chapter 4).
DICHOTOMOUS KEY TO SKULLS IN BARN OWL PELLETS

1. a. Teeth or tooth sockets present; skull without prominent ridge of bone forming an eye socket; skull of relatively thick bone........................................................................................................ Go to 2
   b. Lacking teeth and tooth sockets; skull with prominent ridge of bone forming a complete eye socket; skull of relatively thin bone........................................................................................................ (bird) Class Aves

2. a. No gap (diastema) between incisors and cheek teeth (Order Insectivora) ................................................................. Go to 3
   b. Gap (diastema) between incisors and cheek teeth (Order Rodentia) ........................................................................ Go to 7

3. a. Zygomatic arch complete, skull flat and broad (moles, Talpidae) ............................................................................ Go to 4
   b. Zygomatic arch not complete, skull not flat and broad (shrews, Soricidae) ................................................................. Go to 5

4. a. Upper teeth 10 on each side; mandibular teeth 8 each .......................................................... (SE mole) Scalopus
   b. Upper teeth 10 on each side; mandibular teeth 11 on each side .......................................................... (NW mole) Scapanus

5. a. Skull 1.0 to 1.5 cm total length; upper teeth 9 on each side................................. (least shrew) Cryptotis
   b. Skull greater than 1.5 cm total length; upper teeth 10 on each side .......................................................... (shrew) Sorex

6. a. Skull robust; second and third teeth of same size and larger than fourth and fifth teeth, which are also the same size; sixth tooth minute and hidden from lateral view .............................................. (short-tailed shrew) Blarina
   b. Skull delicate; second through fifth teeth not distinctly paired by size but almost uniform; sixth tooth minute but clearly visible from lateral view ........................................................................................................... (cotton rat)

7. a. Infraorbital canal small, inconspicuous ......................................................................................... Go to 8
   b. Infraorbital canal obvious, vertically elongate; three lower molariform teeth per side ..................... Go to 9

8. a. Upper incisors distinctly grooved ............................................................................................... (pocket mouse) Perognathus
   b. Upper incisors not distinctly grooved ............................................................................................. (pocket gopher) Thomomys

9. a. Skull flat and broad; cheek teeth acutely angled and may appear as one continuous tooth...........
   b. Skull generally rounded; cheek teeth lobed or rounded and easily distinguished individually ........ (pine vole) Microtus

10. a. Upper incisors distinctly grooved ...................................................................................... (harvest mouse) Reithrodontomys
    b. Upper incisors not distinctly grooved ....................................................................................... Go to 11

11. a. Posterior edge of palate ending well beyond last cheek teeth .................................................. Go to 12
    b. Posterior edge of palate ending even with or slightly beyond last cheek teeth ....................... Go to 14

12. a. Upper incisors notched, anterior palatine foramina extend well beyond anterior edge of cheek teeth ................................................................. (mouse) Mus
    b. Upper incisors not notched, anterior palatine foramina do not extend well beyond anterior edge of cheek teeth ........................................................................................................... (house mouse) Mus

13. a. Posterior palatine foramina obvious and located just beyond last cheek teeth ............... (rice rat) Oryzomys
    b. Posterior palatine foramina minute and located between second pair of cheek teeth ........... (rat) Rattus

14. a. Zygomatic plate undercut and having a distinct dorsal protrusion; second and third pair of cheek teeth sigmoid or “s” shaped ................................................................. (cotton rat) Sigmodon
    b. Zygomatic plate not undercut; cheek teeth not sigmoid .......................................................... (deer mouse) Peromyscus
CHAPTER 6: ENERGY USE IN ECTO- VERSUS ENDOHERMS

Objectives:
1. Observe an important difference in the physiology of ectotherms and endotherms;
2. Conduct a controlled laboratory experiment and collect data for lab report.

A) For the domestic mouse:
You will use the quantity of oxygen used as a measure of metabolic rate. Use a makeshift volumeter (a device that measures changes in the total volume of gas at a constant pressure) to determine the amount of oxygen used at two different temperatures and quantify how temperature affects metabolic rate of a domestic mouse.

1. Place a small amount of soda lime in the bottom of a flask and put cotton on top of the lime so that when you put the mouse in the flask, it will not sit directly on the lime. The lime will absorb much of the CO₂ exhaled by the mouse.

2. Weigh the flask (with cotton and lime) before and after you add the mouse to determine the weight of the mouse to the nearest gram (g).

3. Measure the temperature within the flask to determine “room temperature”.

4. Allow the mouse 5 to 10 min to settle down. You want to measure resting metabolic rate.

5. Attach the pipette to the flask via a rubber stopper, hose, and glass tube. Submerge the tip of the pipette in a small beaker of water. Ensure that you have a good seal between the pipette and flask (use Vaseline), but do not apply Vaseline to the stopper-flask interface.

6. Close the stopper. When water reaches a gradation mark on the pipette, note the mark as your initial reading and begin timing for 3 min. Note the behavior of the mouse.

7. After 3 min, record the change in water level within the pipette from your initial reading to estimate the quantity of oxygen used.

8. Repeat the room-temperature experiment twice more, for a total of three estimates. Try to ensure that mouse behavior is consistent among replicates, but note any differences.

9. Use a plastic tub filled with ice and partially filled with water to create an ice bath. Place the volumeter inside the ice bath. Monitor air temperature within the volumeter until it reaches ~5°C. Repeat steps 5 through 8.

10. Convert volume change of oxygen to metabolic rate for each estimate:
\[
\frac{a)}{ml \ O_2 \times \ 60 \ min}{3 \ min} = \frac{ml \ O_2}{hr}, \quad b) \ \text{metabolic rate} = \frac{ml \ O_2}{hr} \div \frac{hr}{g}
\]

11. Determine mean and standard deviation of the domestic mouse metabolic rate for each temperature. Prepare a graph of your findings in proper scientific format that contrasts metabolic rate at the two temperatures you studied.
B) For the southern leopard frog:
The amphibian’s metabolic rate will be approximated by its breathing rate, so your comparison between the mouse and frog will not be via differences in oxygen consumption, but rather by the general relation between metabolic rate and temperature.

1. Get a southern leopard frog already held within a small cage that contains a small amount of water to keep it moist (it should be able to sit with its head out of water). Insert a thermometer into the cage to determine “room temperature”.

2. Begin timing and count the number of times the floor of the mouth lowers (= buccal pumps) in a 60 s period. Note the behavior of the southern leopard frog during the minute.

3. Repeat the room-temperature experiment twice more, so that you have a total of three counts of buccal pumps. Try to ensure that southern leopard frog behavior is consistent among replicates, but note any differences.

4. For cooler temperatures, place the frog cage into a plastic tub that contains an ice bath. Monitor the temperature within the cage until it reaches approximately 5°C. Do not add ice directly into the cage! Only pack ice around the outside.

5. Repeat steps 2 through 3, noting and recording the number of buccal pumps and the behavior of the southern leopard frog during each trial.

6. Calculate the mean and standard deviation of the buccal pumps for each temperature. Prepare a graph of your findings in proper scientific format that contrasts the number of buccal pumps at the two temperatures you studied.

Endothermy/ectothermy lab report guide
Prepare a lab report that describes your experiment and findings. This assignment is worth 50 points and provides you the opportunity to practice working with scientific data and preparing a formal scientific report. Organization and proper formatting are critical components of scientific writing, so you must pay special attention to them as you prepare your lab report. The grading rubric for your lab report can be viewed on the last page of your lab manual. Note that many of the points for this assignment are associated with proper scientific formatting.

Your study objective is to compare the metabolic responses of ectotherms and endotherms to a change in ambient temperature. With this objective in mind, follow instructions below (make sure you get data for a southern leopard frog and domestic mouse during lab to use in your lab report).

Rules for lab reports:
1. Follow instructions in the lab manual appendices and rubric to the detail (Appendices I through IV).
2. Look up proper scientific names for the southern leopard frog and domestic mouse and use them properly in your report (Appendix I).
3. Compose illustration (i.e., Figure) of the apparatus used to measure the metabolic rate of the domestic mouse for use in the methods section (Appendix II).
   a. Illustration can be a high quality photograph with an uncluttered background or a computer-generated “drawing”
b. Properly label all features of the domestic mouse apparatus in the illustration.
c. Prepare a proper figure caption.
d. The illustration should “stand alone”, meaning it should be understandable without reading the text of the report.
e. The illustration should take the place of excess verbiage in your report (a picture is worth a thousand words). Instead of repeating all the details of the apparatus in text, simply summarize your use of the apparatus briefly and refer to the figure (Appendix V).
f. You do not need an illustration of the southern leopard frog apparatus, because it is easily described in text.

4. Graph the average metabolic rate of the domestic mouse (Appendix II).
   a. Include the mean and error bars for each temperature tested based on the standard deviation of your three measurements (Appendix III)
   b. Graph the data from the two temperatures on the same graph for comparison

5. Graph the average number of buccal pumps for the southern leopard frog (Appendix II).
   a. Include the mean and error bars for each temperature tested based on the standard deviation of your three measurements (Appendix III)
   b. Graph the data from the two temperatures on the same graph for comparison

6. Incorporate two primary references that are recent and directly relevant to study/report, handed in as photocopies direct from the journal or “.pdf”-format printouts (Appendix IV).
   a. Must be articles you find on your own, not ones already assigned for class
   b. Must be directly relevant to metabolism of endotherms versus ectotherms and relatively recent, published since 1 January 2000.
   c. Must be handed in as photocopies made directly from the journal or “.pdf” format printouts
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CHAPTER 7: ANCESTRAL METAZOANS

PHYLUM PORIFERA

Of all animal phyla, members of phylum Porifera have the simplest body plan and are considered the most ancestral living metazoans. Poriferan (sponge) anatomy has low complexity, with only a cellular level of organization. This means cells live relatively independently of each other and are not organized into tissues or organs, although groups of specialized cells are referred to as incipient tissues. Poriferans have three main cell types: choanocytes, archaeocytes, and pinacocytes. Choanocytes are only found in poriferans. Cells of different types work together to perform some bodily functions (e.g. feeding), yet have independence as well (e.g., digestion is cellular).

Adult sponges are sessile filter feeders, whereas sponge larvae are motile, but only for a short time. Sponges have three types of water-flow morphology and two types of non-cellular, structural features: (1) protein (collagen) skeleton and (2) calcareous or siliceous spicules. Water-flow morphology and structural features differ among taxa. The bodies of sponges either have no symmetry (asymmetrical) or radial symmetry.

Sponges are closely related to choanoflagellates, a group of protozoans (single-celled organisms). The structure of a choanoflagellate is strikingly similar to that of a choanocyte and some choanoflagellates are colonial. These similarities as well as molecular (genetic) evidence indicate an evolutionary link between choanoflagellates and poriferans. Symbiosis between colonial choanoflagellates and other types of protozoans (e.g., amoebas) may have led to the evolution of sponges. Hence, the link between choanoflagellates and sponges is likely the link between single-celled organisms (protozoans) and multi-celled animals (metazoans).

All poriferans are aquatic and most are marine. Filter feeding causes them to contact a large amount of water during their lives (a 1-cm wide and 10-cm tall sponge filters about 20 l [~5 gal] per day). Sponges are considered to be indicators of good water quality because they have such extensive contact with the surrounding water, which creates high potential to accumulate contaminants.

EXHIBITS FOR PHYLUM PORIFERA

1. Bath Sponge: These sponges are fished commercially. Which structural feature is lacking? What is the body symmetry?

2. Spongilla sp. (live): Examine this freshwater sponge under a dissecting scope. Are both structural features present? Are gemmules present? What are gemmules and how do they permit freshwater sponges to survive the harsh conditions of winter?

3. Sponge fossil: Much of what is known about ancient animal life comes from the fossil record. Examine the portion of this sponge fossil circled in orange. What part of the sponge was fossilized? Why is this the only part preserved? What does this imply regarding the completeness of the fossil record with regard to poriferans? What about other animals?

4. Sponge specimens: observe the diversity of other sponge specimens.
5. **Grantia** dissection and microscope slides:

   a. **Dissection**: determine the water-flow morphology for this specimen (work in groups of 3 or 4) and locate the **spongocoel**, **osculum**, and **ostia**. View dissected pieces of sponge under dissecting and compound microscopes. Compare observations of your dissected specimen with features you can observe in microscope slides (below). Note the absence of tissues and organs housed in a body cavity (coelom).

   b. **Microscope slides**: (c. s./l. s. slide and w. m. slide; for future reference, c. s. = cross-section; l. s. = longitudinal section; and w. m. = whole mount). What structural features are present? How does their chemical structure differ? Find the cells that line the radial canals visible in the c. s. Which of the three cell types are these? What is their functional role in sponge feeding? What is the water-flow morphology?

**PHYLUM CNIDARIA**

Members of phylum Cnidaria (cnidarians) also have a simple body plan and they are considered relatively ancestral, but cnidarians have a **tissue-level** of organization and are **diploblastic**, meaning they have two tissue layers (a.k.a. germ layers): (1) **ectoderm** (epidermis) and (2) **endoderm** (gastrodermis). There is also a non-cellular layer between the two tissue layers (mesoglea). **Cnidocytes**, which bear stinging organelles known as **nematoctysts**, are unique to members of this phylum. Cnidarians have **radial symmetry**.

Cnidarians all share a basic anatomical resemblance, but there are sessile (**polyp**) and free-swimming (**medusa**) forms that are often present as distinct life stages within a given species. However, some cnidarians have only the polyp stage (e.g. hydra and corals) or only the medusa stage (e.g. some jellyfishes). Some cnidarians are colonial. In some cases, multiple individuals share a gastrovascular cavity. Also, some individuals in a colony may be specialized for asexual reproduction.

All cnidarians are aquatic and most are marine but, as with poriferans, some inhabit freshwater. Some cnidarians have symbiotic relationships with algae that live inside them. The algae provide an energy supplement to the cnidarians via photosynthesis and the cnidarians provide protection and a source of P, N, and CO\(_2\) for the algae.

**EXHIBITS FOR PHYLUM CNIDARIA**

1. **Hydra sp.** (c. s. and w. m. with budding slides) **Class Hydrozoa**: Identify the **gastrodermis (endoderm)**, **epidermis (ectoderm)**, and **mesoglea**. Is this a polyp or medusa? Is budding sexual or asexual? What are ways in which cnidarians with only a polyp stage reproduce?

2. **Hydra sp.** (live specimens) **Class Hydrozoa**: Use a plastic dropper to suction a specimen out of the container. Place it with some water on a well slide and cover it with a cover slip. Note its movements and ability to change the length of its body axis. Where on this hydra would there be a high concentration of cnidocytes?

3. **Obelia** (w. m. slide) **Class Hydrozoa**: Identify the **tentacles, radial canals**, and **gastrovascular cavity**. Where is the mesoglea? Is this animal a polyp or medusa? What are ways in which cnidarians with both a polyp and medusa stage reproduce? How does reproduction differ between stages?
4. **Metridium dissection, Class Anthozoa**: locate the tentacles, mouth, oral disc, pharynx, acontia, retractor muscles, gonads, and pedal disc. Which of these represent tissues? How does the level of organization compare to the sponge (*Grantiia*)?

5. **Skeletons of stony corals, Class Anthozoa**. Reef-forming corals are composed of colonies of many polyps. What is the chemical composition of these coral skeletons? Is the hard part of a coral living or nonliving (i.e., cellular or non-cellular)? Where on the skeleton do polyps reside? Coral reefs are declining due to eutrophication (increasing nutrient availability caused by pollution), sedimentation (decreased water clarity), mechanical damage, over fishing, and greenhouse gas buildup (global warming). These stressors cause coral bleaching. Symbiotic algae account for the color of the coral, but stressors such as ocean warming cause algae to abandon the polyps, removing their color as well as their supplemental food source. Thus, abandoned polyps starve. Greenhouse gases, especially CO₂, also increase ocean acidity. Corals are impacted by increased acidity because it limits availability of calcium and increases reef dissolution, making it more difficult for reefs to be built and maintained. Loss of coral reefs has major implications for global biodiversity because the energetically efficient, mutualistic relationship between coral and algae creates a productive and structurally complex habitat that, in turn, supports an inordinate number of unique species. Without coral reefs, the same ocean areas would be non-productive and have little, if any, habitat structure, which would eliminate the majority of associated species and greatly diminish global biodiversity and ocean productivity.

6. **Dimorphism and Polymorphism**: observe examples of cnidarians with dimorphic life histories (e.g., *Obelia* Class Hydrozoa and *Aurelia* sp., Class Scyphozoa) and other cnidarians with polymorphic colonies (e.g., Class Hydrozoa).
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CHAPTER 8: ANCESTRAL PROTOSTOMES

PROTOSTOMIA

Triploblastic protostomes are more complex animals than poriferans or cnidarians. They have three primary germ layers—ectoderm, mesoderm, and endoderm. Protostomes also have organs (composed of tissues) organized into organ systems. However, Protostomia is a very diverse group including less complex animals as well as some that are extremely complex. For example, protostomes may have no body cavity (such animals are acoelomate), a “false” body cavity (such animals are pseudocoelomate), or a “true” body cavity (such animals are coelomate). You will see examples of all of these in this lab.

The group Protostomia is a major division of triploblastic animals (the other being Deuterostomia). Although Deuterostomia includes larger animals we are more familiar with (including ourselves), Protostomia includes a much greater number of species and much greater taxonomic diversity. Protostomes can be distinguished from deuterostomes by distinctive features of early embryological development that include: (1) spiral cleavage, (2) a mosaic embryo (determinate cleavage), (3) the blastopore becomes the mouth, and (4) the body cavity (i.e., coelom, if present) is formed via schizocoely.

PHYLUM PLATYHELMINTHES

Platyhelminthes includes flatworms, tapeworms, and flukes. Some flat worms are free-living and others are parasitic. Free-living forms are generally aquatic or found in moist terrestrial environments. Parasitic forms are generally endoparasites. Platyhelminthes have an incomplete digestive tract that does not end in an external opening or anus. They are acoelomate, lacking a body cavity, that is, the digestive tract is surrounded by solid tissue (mesoderm) rather than a coelomic space.

EXHIBITS FOR PHYLUM PLATYHELMINTHES

1. Planaria (live, preserved specimens, e. s. and w. m. slides) Class Turbellaria: Examine live and carbon-fed preserved specimens, and whole mount slide to understand body morphology and digestive tract anatomy. Examine the cross section slide to understand the acoelomate body anatomy. Identify the cellular ciliated epidermis (ectoderm), longitudinal, pharyngeal, and parenchymal muscles (mesoderm), and columnar epithelium (endoderm). Is there internal symmetry? Given their status as acoelomates, what is the advantage of having such a highly branched digestive tract? How do flatworms eliminate digestive wastes?

2. Tapeworm scolex (w. m. slide) Class Cestoda: observe the scolex, which is a derived feature characteristic of the Platyhelminthes class Cestoda. What other derived features have made members of this class specialized endoparasites?

3. Flukes (preserved specimens) Class Trematoda: Examine specimens and slides representing this Platyhelminthes class of parasites.

PHYLUM NEMATODA

Nematodes have a complete digestive tract that ends with an anus. They are pseudocoelomates. Their digestive tract is surrounded by a fluid-filled space (the pseudocoelom), which is incompletely lined by (mesodermal) peritoneum. That is, only the ectoderm is lined by mesoderm. Make sure you understand how the pseudocoelom functions in osmoregulation, locomotion, and circulation. Nematodes are extremely abundant throughout the world in virtually all habitat types. There are free-living and parasitic forms, but parasites are best known because of their impacts on human health and agriculture. For example, the Trichina worm sometimes present in under-cooked pork (causing Trichinosis) is a
nematode. The extreme abundance of nematodes indicates the success of their anatomical design. What factors do you think make this phylum so successful?

EXHIBITS FOR PHYLUM NEMATODA

1. *Ascaris* dissection and microscope slides:
   a. **Dissection**: Find the following structures via observation and dissection and understand their function: external features (use dissecting scope) **cuticle**, **mouth**, and **anus**; internal features (dissect and view under dissecting scope) **pharynx**, **intestine**, **gonads**, and **body cavity (pseudocoelom)**. Determine anterior, and posterior body regions. Compare observations of your dissected specimen with features you can observe in microscope slides (below). Also, reflect on how anatomical complexity compares with ancestral metazoans (i.e., poriferans and cnidarians).
   
   b. **Microscope slides**: (c. s. slide). Compare the cross-section with that of a planarian (phylum Platyhelminthes). Note that reproductive organs occupy much of the internal space. Identify the acellular **cuticle** (composed of collagen), **hypodermis** (ectoderm), **longitudinal muscles** (mesoderm), **intestinal lining** (endoderm), and **pseudocoelom** (body cavity between mesoderm and endoderm). Is there internal symmetry?

2. **Vinegar eels** (live specimens). Examine these using a microscope slide, cover slip, and compound light microscope. Vinegar eels are representative of the size of most species of nematodes living in soil, water, or as parasites of other organisms. Note the thrashing movement accomplished by the action of the longitudinal muscles working against the **hydrostatic skeleton**. What is the limitation of having only longitudinal muscles? Based on the success of nematodes, is this really a “limitation”? What is the importance of the nonliving cuticle of vinegar eels to their existence in a harsh physical environment?

3. **Trichinella spiralis** (slide). *Trichinella* worm larvae can encyst in the muscles of swine and game animals. They are liberated after consuming raw or undercooked infected meat. The worms mature and reproduce in the gut and new larvae migrate to the muscles (& other organs) where they encyst awaiting another predator. Symptoms of trichinosis become about 3 weeks after initial infection.

PHYLUM ANNELIDA

Annelids display a repetition of body segments (**metamerism**) that increases the dexterity of the **hydrostatic skeleton** and improves resistance to injury. The annelid hydrostatic skeleton combines with longitudinal and circular (smooth) muscles and setae to facilitate sophisticated movements, such as those associated with burrowing. **Setae** can be extended and used to anchor an annelid in place (have you ever attempted to pull an earthworm from its burrow?). Annelids inhabit marine, freshwater, and moist terrestrial environments. Most are free-living but some (e.g., leeches) are ectoparasites. Annelids have a complete digestive tract and are **coelomates**. That is, their digestive tract is surrounded by a space (the **coelom**) that is completely lined by mesodermal peritoneum (mesoderm lines the ectoderm and endoderm). The coelom and closed circulatory system are major reservoirs for body fluids.

EXHIBITS FOR PHYLUM ANNELIDA

1. **Assorted annelids** (preserved specimens): examine annelid specimens. Recognize the three main classes of this phylum: **class Polychaeta**, **class Oligochaeta**, and **class Hirudinida**.
2. *Lumbricus* dissection and microscope slides:

   a. **Dissection**: Find the following structures via observation and dissection and understand their function: external features (use dissecting scope) *setae*, *prostomium*, *mouth*, *clitellum*, and *anus*; internal features (dissect and view under dissecting scope) *pharynx*, *esophagus*, *crop*, *gizzard*, *intestine*, and *body cavity (coelom)*. Determine ventral, dorsal, anterior, and posterior body regions. Compare your observations with features you can see in the microscope slides. Also, reflect on how anatomical complexity compares with ancestral metazoans (i.e., poriferans and cnidarians).

   b. **Microscope slides**: (c. s. slide). How does the coelomate cross section differ from that of acoelomates and pseudocoelomates? Is there internal symmetry? Find the *cuticle*, *epidermis* (ectoderm), *setae*, *smooth and longitudinal muscles* (mesoderm), *peritoneum* (mesoderm), *intestinal epithelium* (endoderm), and *coelom* (body cavity within mesoderm).
CHAPTER 9: DIVERSITY IN PHYLUM MOLLUSCA

The phylum Mollusca is the second most diverse phylum (behind Arthropoda). Molluscs are triploblastic coelomates and protostomes exhibiting the following traits in early embryological development: (1) spiral cleavage, (2) a mosaic embryo (determinate cleavage), (3) the blastopore becomes the mouth, and (4) a coelom formed via schizocoely. All molluscs share a two-part body plan consisting of a head-foot and visceral mass. Molluscs also have a fold of epidermal tissue called the mantle that has a variety of functions. Most molluscs have a radula and shell. The phylum includes eight classes, three of which—Gastropoda, Bivalvia, Cephalopoda—are emphasized here. Most molluscs are aquatic, being widespread in marine and freshwaters. Gastropods are also widespread in terrestrial environments, albeit mostly in moist habitats.

EXHIBITS FOR PHYLUM MOLLUSCA
1. Observe the specimens from the Mollusca survey bucket. Identify members of the following classes: Polyplacophora, Monoplacophora, Gastropoda, Cephalopoda, and Bivalvia.

CLASS GASTROPODA
What does the name “gastropod” indicate about snail morphology? Gastropods are widespread in all aquatic environments and moist, terrestrial environments. What features of gastropods allow them to inhabit terrestrial environments whereas other phyla we have studied so far and other classes of phylum Mollusca are primarily limited to aquatic environments?

EXHIBITS FOR CLASS GASTROPODA
1. Land snail (preserved specimens) – examine the external anatomy of a terrestrial gastropod. Be sure you can identify the head, foot, visceral mass, eyestalks, shell, and mouth. Refer to your text to visualize how their internal anatomy relates to these external features.

2. Radula slide – How is this structure used by gastropods in feeding?

3. Assorted shells and live specimens – Are shelled gastropods bivalves or univalves? Is there evidence of coiling? How does coiling of the shell differ from torsion? Identify the aperture, apex, and whorls of the shells. Nearly all gastropod shells have right-handed (dextral) coiling, as opposed to left-handed (sinistral) coiling. Hold a shell with the apex pointing up. If the aperture (opening) is on the right-hand side, then it is a dextral shell. “Dominance” of dextral shells is an artifact of the way shell coiling was initially described and likely reflects a human bias towards right-handedness. Look around the classroom for examples of live gastropods in aquaria. Can you see a radula or foot in action?

CLASS BIVALVIA or PELECYPODA
What is the meaning of the name “Bivalvia”? What about Pelecypoda? What anatomical features indicate bivalves are molluscs despite the fact they are very different from other classes? Bivalves are widespread in aquatic habitats including marine and freshwaters. Freshwater bivalves were particularly abundant and diverse in North America, but the majority of species are now extinct or endangered because of pollution, stream degradation, and invasions of nonnative bivalves such as the zebra and quagga mussels (Dreissena polymorpha and D. rostriformis bugensis). As with poriferans, bivalves filter so much water that they have high potential to accumulate contaminants in their bodies, so most species are associated with relatively clean aquatic habitats.
**EXHIBITS FOR CLASS BIVALVIA**

1. **Assorted bivalve shells.** Bivalve shells typically have three layers: 1) the outer *periostracum* is organic and largely composed of proteins. It is best developed in freshwater molluscs, where it is resistant to acidic conditions; 2) the middle *prismatic layer* is a dense accumulation of calcium carbonate crystals; 3) the inner *nacreous layer*, also called nacre or mother-of-pearl, is formed by thin layers of calcium carbonate continuously deposited by the mantle. On some shells, it should be possible to see all three layers. Name the structure that holds the two valves of the shells together near the *umbus*. What structures are involved in closing the shell? These are what you eat when having scallops. Can you find evidence of their attachment inside the shells?

2. **Mussel dissection:** Find the following structures via observation and dissection and understand their function: *hatchet foot, mantle, gills, labial palps, umbo, posterior and anterior adductor muscles, and incurrent and excurrent apertures*. How are these structures involved in bivalve filter feeding? Determine ventral, dorsal, anterior, and posterior body regions.

**CLASS CEPHALOPODA**

What is the meaning of the name “Cephalopoda”? Cephalopods are found only in marine habitats. Compared to other invertebrates, cephalopods have a complex morphology and are highly mobile. Some species may also become large. What features distinguish cephalopods from other molluscs or allow them to be more mobile or larger than those of previously studied taxa?

**EXHIBITS FOR CLASS CEPHALOPODA**

1. **Assorted cephalopod specimens.** Examine these to appreciate the full range of differences in the external structure of different groups of cephalopods. Cephalopods are fast-moving predators, having a *closed circulatory system, direct development* (no larval stage), and *sophisticated eyes*. Their eyes are evolutionarily convergent in structure and function with those of vertebrates. Cephalopods also show great variation in shell structure: nautili have sophisticated shells, squid and cuttlefish have reduced internal shells (mantles), and octopi have no shell. Identify the *head, foot, mouth, funnel, tentacles, and arms* in all specimens.

2. **Preserved squid specimens.** Identify the following structures: *eyes, arms, and tentacles of the foot*, the many small *sucker disks* on the surface of the arms and tentacles, the *mantle tissue, body fins, funnel, mouth, and jaw/beak*. Do not dissect, but visualize how their internal anatomy relates to these external features. Determine the ventral, dorsal, anterior, and posterior regions of the squid and arrangement of the head-foot versus the visceral mass.
CHAPTER 10: DIVERSITY IN PHYLUM ARTHROPODA

Arthropoda is the largest phylum in the kingdom Animalia, meaning it includes the most known species. Arthropods are triploblastic coelomates and protostomes. Take time during this lab to review what these terms mean and what characteristics are associated with them. All arthropods share three hallmarks: (1) chitinous exoskeletons, (2) jointed appendages, and (3) body segmentation (metamerism), with segments often combined into tagmata. What are evolutionary advantages of these features? What are disadvantages or limitations? There are four living subphyla: (1) Chelicerata; (2) Myriapoda; (3) Crustacea; and (4) Hexapoda. Main distinguishing features of subphyla are: (1) number and arrangement of tagmata and (2) number and types of paired appendages. Separation of this phylum into major subphyla should remind you of phylum Chordata and indicate to you that phylum Arthropoda includes great diversity (i.e., many very different animals). What does this tell you about the evolutionary flexibility of the arthropod hallmarks? Arthropods are not only the most diverse group of animals, but they represent the dominant invertebrate phylum in terrestrial environments. How do arthropods succeed in dry environments where other invertebrates fail?

SUBPHYLUM CHELICERATA

As with arthropods in general, chelicerates are widespread among aquatic and terrestrial environments. The following characters distinguish chelicerates from other arthropods: (1) unsegmented cephalothorax and abdomen; (2) six pairs of cephalothoracic appendages including: (a) one pair of chelicerae (mouthparts); (b) one pair of pedipalps; and (c) four pairs of walking legs. Other important features: (3) absence of antennae; (4) chelicerae instead of mandibles.

EXHIBITS FOR SUBPHYLUM CHELICERATA

1. *Limulus* (horseshoe crab dried and preserved specimens) Class Merostomata: the name “crab” has no taxonomic significance and does not necessarily imply relatedness. For example, the horseshoe crab is classified as a member of subphylum Chelicerata whereas what most people think of as “true crabs” are classified as members of subphylum Crustacea. In addition to chelicerate features listed above, horseshoe crabs have 5 to 6 pairs of abdominal gills and a terminal, spike-like telson. Note the carapace, eyes, chelicerae, pedipalps, walking legs, and mouth. Modern horseshoe crabs appear little changed from 400,000,000-year-old fossils. Thus, they are referred to as “living fossils”. What environmental conditions would facilitate an animal remaining virtually unchanged for an evolutionarily-long period of time?

2. [www.horseshoecrab.org](http://www.horseshoecrab.org) (web site): Prior to lab, visit this web site. Horseshoe crabs have exceptional ecological, medical, and economic significance. Their breeding migrations every spring are an important resource for many other animals that prey on their eggs (laid in the sand) and their larvae and juveniles (which migrate from the beach to the ocean and exist in the ocean as zooplankton). The annual spring migration of many shorebirds corresponds to the breeding migration of horseshoe crabs, which allows the shorebirds to refuel during their trek. This in turn provides recreational and economic opportunities for humans who either are attracted to shorebirds (birdwatchers) or are attracted to birdwatchers (merchants).

Perhaps even more notably, horseshoe crabs are critical for promoting public health. Their blood is used to test all injectable medication for bacterial contamination. Horseshoe-crab blood clots in the presence of bacterial contamination. This provides an easy, inexpensive, and reliable indicator of unsafe samples. No other substitute test is known. Horseshoe-crab blood is routinely harvested from horseshoe crabs. Individual crabs commonly “donate” blood many times throughout their lives.

3. *Argiope* sp. (garden spider preserved specimens) Class Arachnida: Use a dissecting scope to examine the body of this common orb-weaving spider. Note the general chelicerate features, particularly the tagmata, eyes, chelicerae, pedipalps, and four pairs of walking legs. Chelicerae are associated with venom glands for prey capture. Also, note the spinnerets (organs of silk production) and the openings leading to the book lungs (respiratory organs).
4. **Ticks and mites** (combined w.m. slide) **Class Arachnida**: Ticks and mites are distinguished from all other chelicerates in having their cephalothorax and abdomen fused. Mites are found almost everywhere (like Nematodes). For example, they are common inhabitants of house dust and human feces. Ticks are larger than mites and are ectoparasites of vertebrates (like Hirundinidans). Tick-transmitted diseases include: typhus, Rocky Mountain spotted fever, and Lyme disease.

5. **Arachnids** (dried and preserved specimens) **Class Arachnida**: examine other representatives of this legendary class including tarantulas, scorpions, vinegarroons, and ticks. Identify characteristic four pairs of walking legs, pedipalps, and chelicerae.

**SUBPHYLUM MYRIAPODA**

Myriapods are distinguished by (1) one pair of antennae, (2) adult appendages always uniramous (unbranched); (3) tracheae (air-conducting tubes) used for respiration.

**EXHIBITS FOR SUBPHYLUM MYRIAPODA**

1. **Assorted specimens** (live millipedes, dried and preserved centipedes and millipedes): examine specimens and understand the basic distinction between **class Diplopoda** (millipedes) and **class Chilopoda** (centipedes). Though most species are harmless to humans, centipedes have poison claws associated with their maxillipeds. Some large tropical species can inflict a painful bite. In contrast, millipedes chemically defend themselves with secretions of the repugnatorial glands on the sides of the body. Some millipedes have an almond-like odor, indicative of a hydrogen-cyanide based defense. What anatomical features correspond to differences in speed and forage?

<table>
<thead>
<tr>
<th>Class</th>
<th>Leg pairs per body segment</th>
<th>Body form</th>
<th>Speed of movement</th>
<th>Forage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chilopoda</td>
<td>1</td>
<td>Dorsoventrally flattened</td>
<td>Fast</td>
<td>Animal prey</td>
</tr>
<tr>
<td>Diplopoda</td>
<td>2</td>
<td>Cylindrical</td>
<td>Slow</td>
<td>Plant matter</td>
</tr>
</tbody>
</table>

**SUBPHYLUM CRUSTACEA**

This subphylum is a major group of arthropods and is highly diverse. Crustaceans are mainly restricted to aquatic environments although some taxa inhabit moist terrestrial environments. Most are free-living but some are parasitic. Crustaceans are distinguished by (1) two pairs of antennae; (2) one pair of mandibles; (3) two pairs of maxillae; (4) gills (typically associated with some appendages); and (5) biramous (two-branched) appendages. Most appendages were ancestrally biramous, but modified in modern crustaceans. However, most derived crustaceans still exhibit some biramous appendages. The largest and best known class of Crustacea is **Malacostraca**, which includes isopods (pill bugs, sow bugs, roly-polys), amphipods, krill, and decapods (shrimp, crayfish, lobster, “true” crabs).

**EXHIBITS FOR SUBPHYLUM CRUSTACEA**

1. **Crustaceans** (preserved and dried specimens): examine various specimens of crustaceans from **class Malacostraca**. Do you find representatives of any other class?

2. **Gammarus** (amphipod, w. m. slide) **class Malacostraca**: amphipods serve as examples of “typical” malacostracan crustacean. Look for general crustacean features including biramous appendages.

3. **Crayfish dissection** (preserved specimen) **class Malacostraca**: Note each body segment has paired, jointed appendages. Identify traits unique to crustaceans (above) as well as walking legs (including chelipeds and associated chelae), abdominal swimmerets, telson, and uropods. Remove the carapace to identify the: heart, brain, stomach, digestive gland, and gills. Which appendages are biramous?
4. **Live Artemia** (brine shrimp) **class Branchiopoda**: Examine these branchiopods under a dissecting microscope. Cysts (resistant, overwintering “eggs”) of these animals are the basis for the brine shrimp fishery in the Great Salt Lake that is valued at up to $200 million some years. Most cysts are sold as fish food for young fish in aquaculture facilities (fish hatcheries). Cysts stored dry remain dormant. When immersed in water, they hatch and are excellent forage for larval fish. *Artemia* spp. are dominant primary consumers in the Great Salt Lake and are a critical food source for shorebirds and waterfowl. *Artemia* spp. are extreme hypoosmotic osmoregulators. Why is this critical to their existence?

5. **Daphnia** of **class Branchiopoda** and **Cyclops** of **class Maxillopoda** (combined w.m. slide): Many crustaceans, although either microscopic or barely macroscopic, are abundant and important within aquatic food webs. *Daphnia* are branchiopods (what is the meaning of this term?) commonly called water fleas and *Cyclops* belong to the group copepods. Both are important primary consumers (eaters of algae) in aquatic food webs. Their total biomass is often enormous and, in the case of copepods, is sometimes estimated to be billions of metric tons! Look for biramous appendages! Look for distinguishing characteristics between classes!!

6. **Barnacles** (shells and preserved specimens) **class Maxillopoda**: What features identify them as crustaceans? Barnacles (like poriferans and corals) transform from free-swimming larva to sessile adults. Larvae resemble those of other crustaceans. Adults use cirri (modified legs) to filter particles from water. Barnacles are monoecious (hermaphroditic). The barnacle penis is greatly elongated (several times the length of their body). Why is this sexual anatomy important?

7. **Lernaea** sp. (anchor worm fish ectoparasite) **class Maxillopoda**: some crustaceans are parasites. Observe trout specimens with *Lernaea* sp. attached to muscle along the side and near fin insertions.

8. **Ostracod** (w. m. slide) **class Ostracoda**: members of class Ostracoda are commonly known as seed shrimp. They live in a chitinous or calcareous bivalve-like shell. Ostracods are by far the most common arthropods in the fossil record (why?), with fossils being found from the Cambrian to the present day.
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CHAPTER 11: DIVERSITY IN PHYLM ARTHROPODA II

SUBPHYLUM HEXAPODA – CLASS INSECTA

Features that distinguish members of class Insecta include: (1) three tagmata—head, thorax, and abdomen; (2) wings (if present) attached to thorax; (3) three leg pairs attached to thorax; (4) specialized paired mouthparts. Insects comprise ~two-thirds of all animal species. The taxonomic level “order” is the most recognizable level of insect classification. Names of most insect orders are based on wing type. The word-root *pter* refers to “wing”, so, order Isoptera (termites) is named for equal-sized (*iso* = same) wings. There are 30 insect orders, but over 90% of insect species are members of either: (1) Hymenoptera (bees, wasps, and ants), (2) Lepidoptera (moths and butterflies), (3) Diptera (“true” flies), or (4) Coleoptera (beetles). You should also recognize: Hemiptera (“true” bugs), Orthoptera (grasshoppers), Odonata (dragonflies), and Thysanura (silverfish). Insects dominate terrestrial and freshwater environments but are rare in marine environments (why?). Many species have aquatic larvae and terrestrial adults. The transition from water to land is usually associated with metamorphosis and molting. Other insects spend portions of their life cycle underground. Most insects are free-living and do not directly impact humans, but some are ectoparasites that may spread disease. Others affect crops.

EXERCISES FOR CLASS INSECTA (continued on the next page)

1. Grasshopper dissection (preserved specimen) class Insecta, order Orthoptera: note the three tagmata, thoracic wings, three pairs of legs, and paired mouthparts (homologues of Insecta). Locate single pair of antennae, mouth, anus, and ovipositor. Remove a portion of the exoskeleton to identify the: crop, colon, and rectum of the digestive system, brain and ganglia of the nervous system, aorta, ostia, and heart of the circulatory system, and gonads. What internal differences do you notice between an insect (this grasshopper) and a crustacean (the crayfish dissected in a previous lab)?

2. Metamorphosis: use your textbook and available exhibits to learn the difference between hemimetabolous and holometabolous development

3. Insect orders: use the dichotomous key to identify the insect specimens to order. Dichotomous keys provide a series of choices. Each pair of choices is called a couplet. The choice you make at each couplet directs you to the next couplet. When you have made the correct series of choices, you end at the appropriate name for your specimen. Be familiar with characteristics that distinguish each order and examine the diversity of 8 insect orders (listed above) with regard to four evolutionary events:
   a. Divergence of wingless insects from other hexapods (Thysanura);
   b. Development of primitive wings that lack a folding mechanism (Odonata);
   c. Development of wing-folding mechanism (Hemiptera, Orthoptera);
   d. Derivation of holometabolous development (Diptera, Hymenoptera, Coleoptera, Lepidoptera)
   e. Draw a cladogram of the insect orders indicating the derived homologs used to denote each clade.
f. Below are terms you will need to know to effectively use the key for insect orders (continued on the next page). Look these up in your textbook or in “Henderson’s Dictionary of Biology”.

   Basal:

   Caudal:

   Distal:

   Halteres:

   Proboscis:

   Pronotum:

   Tarsus:

4. **Ant diversity**: Use photographs and dichotomous key (provided) to identify ants of the family Formicidae to sub-family as directed by your lab instructor.
APPENDIX I – WRITING SCIENTIFIC LAB REPORTS

In science, communication of research results is essential and is most effectively conducted in written form. A general format has been developed for organizing and formatting scientific papers. You will use a simplified version of this for writing two lab reports. Scientific writing is brief, concise, avoids wordiness, and avoids big words unless they are absolutely necessary. Space is always at a premium, so manuscripts are written to be as short as possible. However, they must be long enough so readers can repeat studies and judge their validity. Typical research manuscripts are organized into five sections (described below). Sections organize information in a straightforward way and rapidly direct readers to pertinent information. In your lab reports, use each title exactly as shown here and compose sections following descriptions below. Heading names must appear at the beginning of each section.

INTRODUCTION
The introduction provides context for the research being presented and describes the goals of the study or hypotheses being tested. The introduction explains the why and what of study. It should be brief (2 or 3 paragraphs). It establishes the basis of the research, in other words, it explains why the research is interesting or important. The introduction also establishes what will be tested and what will be learned. It may also briefly summarize important prior research that has led to the research being presented. Introductions always include reference to previous works. When such information is used, its source must be cited using the proper scientific format (Appendix V). Introductions commonly conclude with a statement of study goals including expectations (hypotheses and predictions).

MATERIALS AND METHODS
The methods section is where you tell exactly what you did in enough detail that the reader could repeat your experiment. However, you should avoid unnecessary detail and be brief wherever possible. Any statistics or other means of data analysis must be described because they are part of the methods. Always use an active (first person) voice (e.g. “I put measured. . .”). You are telling the reader what you already did so methods should be written in past tense. Do not number steps or give directions - this is not a cookbook! Use prose to simply and concisely explain your methods. This section may include illustrations of unorthodox or sophisticated equipment used during the study. When you include such figures, cite them using the appropriate format (Appendix V). This section may also include reference to previous works that must be cited using the proper scientific format (Appendix V). However, for simple experiments (such as you will conduct in this course) citations are rarely necessary in the materials and methods section.

RESULTS
In the results section, describe your findings, but do not interpret them. Also, do not reference other studies. The results section is often the shortest section of a manuscript. Figures (graphs, photographs, illustrations, etc.) are commonly used to reduce text and make complicated results easy to visualize (Appendix II). When figures are used, brief summaries must be included in the text of the results section. These summaries do not repeat the data presented in the figure. Rather, they summarize important findings that are most relevant to the study and then cite the relevant figure (Appendix V). Each figure or table is numbered in the order presented (in sequence with any figures presented in materials and methods) and is accompanied by a caption that explains the contents. Use the caption to point out the main purpose of the figure or table and explain any symbols or abbreviations that may be unclear. No part of a figure should be confusing or unexplained (Appendix II).

DISCUSSION
Conclusions about your results are presented here. Provide your interpretation of your findings and discuss their scientific implications to establish the importance of your study. Did your results support your original predictions? Why or why not? Did they bring up any further questions that might be worth pursuing? Also, discuss relevant literature and include citations in the appropriate format (Appendix V). Avoid second-guessing yourself or picking apart your work. Put your best foot forward, but be honest about limitations and uncertainties. The discussion section is critical for any manuscript because it should bring the study together to provide a meaningful take-home message.
LITERATURE CITED

Every work you cite in the text must be referenced in full in this section. Scientists use a standard citation format to ensure that readers can easily obtain references (Appendix V). Each citation must list the author name(s), year of publication, article title, journal name, journal volume, and pages of the article. Articles listed in the literature cited must be organized alphabetically by the last name of the first author. The literature cited section is a main section of a manuscript comparable to the preceding sections and should be formatted in the same way (i.e., formatting should not change between previous sections and the literature cited). For example, font size, font type, and spacing should remain consistent in all manuscript sections.

OTHER LAB REPORT COMPONENTS

Title page: Each lab report should begin with a title page (see example below). The second page should begin with the introduction heading. In other words, the name of the paper, student, and class information are listed on the title page, not in the main body of the paper.

Abstract: Normal scientific articles require an abstract that summarizes the study, but an abstract is not required for lab reports.

Figures: Although figures are incorporated within the body of published scientific papers, this is not done for manuscripts (papers that are submitted for potential publication) partly to make things easier for the authors (the publisher will format the paper how she sees fit, should she decide to accept the manuscript). When a manuscript is prepared, the author places the tables and figures at the end, after the literature cited section. Each table and figure is placed on a separate page. Follow this protocol in preparing your lab report. Figures follow strict formatting guidelines to ensure clarity and readability (Appendix II).

Scientific names: For any species or genus of animal referred to, it is customary to provide the scientific name on first use because common (vernacular) names are not always standardized and may refer to a variety of animals, which would potentially confuse readers and make it difficult for them to replicate your study. In the main text of your lab report, give the scientific name in parentheses after the common name the first time you mention an organism. It is not necessary to give the scientific name on subsequent uses. However, it is necessary to give the scientific name separately for each organism mentioned in figure captions because figures should stand alone.

Scientific names for species include two parts: a genus epithet and a species epithet. The two parts make up the scientific name of a species, following the conventions of binomial nomenclature. The genus epithet comes first and refers to the genus to which the species belongs. This epithet is always capitalized. The species epithet comes second and refers to the species itself. It is never capitalized. Both words are always presented in italics to indicate they are Latinized words (although not all scientific names are technically Latin words). An example is the rainbow trout (*Oncorhynchus mykiss*).

An alternative to using common and scientific names together is to use only scientific names. In this case, generic epithets can be abbreviated after first use as the first initial with a period as in: *O. mykiss*. The species epithet is always written out. However, scientific names should never be abbreviated to begin a sentence as it results in confusing punctuation.

Number formatting: Numbers in text should always be written out if less than ten (as in the number one). Numbers in text of ten or greater should be presented as numerals (as in the number 14). However, numbers in series should always be presented as numbers (as in “there were between 5 and 9 turkeys feeding in the woodlot”). When numbers are presented with units of measurement, they should also be presented as numerals (as in “the sidewinder (*Crotalus cerastes*) was at least 3 m in length”). When presenting a numeric value less than one there should always be a zero in front of the decimal (e.g., “0.5”, not “.5”). There should always be a space between any numeral and its associated units of measurement. There should also be a space between any numeral and any associated symbol (as in “there were < 18 students in the lab”).
**Lab report submission format:** Lab reports should be printed single-sided and all pages should have minimum 2 cm margins with page numbers in the bottom center of the page. All text should be in 12-point font (font type and size must be consistent throughout). Cited articles can be printed double-sided and with more than one page per printed page so long as text remains readable. Hand in your lab report **stapled** with title page first, then body text (introduction, materials and methods, results, discussion, literature cited), then figures in proper order. Cited articles should be stapled separately. The lab report and articles should be clipped together with an appropriately sized binder clip or inserted into a pocketed folder as per your lab instructor’s preference.
The effect of rain on lions of the Serengeti

Lab Report 1
Spring Semester 2007

by
Lord Thompson, Jr.

for
Principles of Zoology II Lab 32219
Friday, 12:00
Instructor: Hoagstrom
APPENDIX II – GRAPHING

When you need to include graphs in your lab reports, you may use any graphing program you wish, but you must produce and turn in graphs as described and illustrated below.

Graphing rules:
• Graphs should be constructed independently by each individual student.
• Graphs must be computer generated.
• Never use color in any capacity within a graph.
• All axes must be labeled (units included in parentheses).
• Graph axes should be constructed within the range of the data (avoid leaving excessive, unused space).
• Show data points for all data presented (not just lines) except in the case of bars.
• Data points are used to represent individual data values, bars represent cumulative (count) data.
• Data graphed with multiple types of lines or bars should be easily distinguished via differing line types, symbols, or shading.
• When different shades, patterns, line types, or symbols are used, include a legend labeled correctly to distinguish them.
• Never include horizontal or vertical gridlines of any kind (i.e., no reference lines).
• Use a white (clear) background only for all graph components.
• When appropriate, include error bars. Be sure to list the type of error estimate (e.g., standard deviation, standard error, data range, confidence interval) in the caption.
• Never include an out box or frame around the graph.
• Font type (e.g., Times New Roman, Arial) must be consistent throughout a graph.
• Make sure all text is readable and do not place text on top of any other feature (line, symbol, other text, etc.) that would obscure it.
• Number figures in the order presented in text.
• Present each graph on a separate page in portrait view (page taller than wide).
• A descriptive figure caption below the graph (no other title) must explain graph contents and distinguish any potentially confusing features (double space caption text) including scientific names for any organisms mentioned, sample size, and explanation of legend (if not obvious from the graph itself).
• All text in your lab report should be double spaced, including text in figure captions.
• Compose each graph in a graphing program (e.g. Excel, Sigma Plot). Paste the finished graph into your word processing program (e.g. Word, Word Perfect) as a picture (paste special). Type a figure caption below graph in a word processing program.
Example point graph that follows the above guidelines:

Figure 1. Change in average mass of domestic rats (*Rattus rattus*) raised on two alternative diets (experimental = cheese and lettuce, control = commercial rat food). A total of 10 rats was raised on each diet. Error bars represent the standard deviation of domestic rat weights.
Example bar graph that follows the above guidelines:

![Bar Graph](image)

Figure 2. Number of aluminum cans of four different types of soft drinks in different locations in the vicinity of Weber State University, Ogden, Utah (campus = Weber State University student union building trash cans; across = a dumpster at a grocery store across Harrison Boulevard from campus; suburbs = a dumpster at a grocery store in South Ogden, Utah; downtown = a dumpster behind restaurants on 25th street, Ogden, Utah). Cans were collected from each location on 10 different days between 2 February and 8 April 2008.
THE MEAN AND STANDARD DEVIATION

The mean of a data set is simply the average of all values. For example, you may have measured growth rates of domestic rats (*Rattus rattus*) eating a certain diet and you may be interested in what the average growth rate was. If you have measured growth in ten domestic rats, simply add their growths together and then divide the total by the number of domestic rats studied (Table 1).

<table>
<thead>
<tr>
<th>Individual domestic rats (<em>Rattus rattus</em>)</th>
<th>Growth in mass over 10 days (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong> ((\sum))</td>
<td><strong>53</strong></td>
</tr>
<tr>
<td><strong>Mean</strong> (total growth / 10 domestic rats)</td>
<td><strong>5.3</strong></td>
</tr>
</tbody>
</table>

As you can see, the mean does not literally represent every individual because growth was variable among domestic rats. For this reason, it is inappropriate to present a mean without an accompanying estimate of the associated variation. The amount of variation relative to the mean is a measure of the accuracy of the mean (means with relatively low variation more accurately represent the majority of individuals in a sample).

There are several potential measures of variance that can be used and they are chosen based on the specific needs of a given researcher. For our purposes, we will use the standard deviation, which is a commonly used measure of variance. The calculation for the standard deviation \(s_j\) is:

\[
s_j = \sqrt{\frac{1}{n-1}(\sum(y_{ij}-y_j)^2)}
\]

where:
- \(j\) = the total sample (all individuals combined)
- \(i\) = individual values (individual domestic rat growth)
- \(\sqrt{}\) = the square root
- \(n\) = the number of individuals (10 in this case)
- \(\sum\) = summation
- \(y_j\) = individual growth measurements
- \(y_{ij}\) = the mean of growth measurements
Thus, the calculation for the standard deviation of the above domestic rat growth data is:

\[
s_j = \sqrt{\frac{1}{9} \left( (5 - 5.3)^2 + (4 - 5.3)^2 + (1 - 5.3)^2 + (8 - 5.3)^2 + (5 - 5.3)^2 + (11 - 5.3)^2 + (2 - 5.3)^2 + (6 - 5.3)^2 + (8 - 5.3)^2 \right) }
\]

\[
s_j = \sqrt{(0.11) (0.09 + 1.69 + 18.49 + 7.29 + 0.09 + 5.29 + 32.49 + 10.89 + 0.49 + 7.29)} = \sqrt{(9.34)} = 3.06
\]

**THE CHI-SQUARE GOODNESS OF FIT TEST**

**Appropriate Uses of the Analysis**

Suppose we have some expected distribution of categories and wish to know whether or not a distribution of observations that fit into each category differs significantly from that expected. For example, we might expect a sample of domestic rats (*Rattus rattus*) to be evenly distributed between male and female categories (50% male, 50% female). The Chi-square (\(X^2\)) test allows us to compare observed distributions with an “expected” distribution and determine whether observed distributions are what would be “expected” based on some sort of reasoning or statistically different from what was “expected”. If they are statistically different, then we may conclude that some factor is influencing the distribution (e.g., in the case of our rats, perhaps longevity differs between sexes).

**CALCULATIONS**

a. Determine the expected frequency for each category by calculating the ratio of observations versus the number of categories.

   \[
   \text{Expected} = (N) (C); \text{ where } N = \text{the number of samples (observations)} \text{ and } C = \text{the number of categories}
   \]

   For example, if we studied ten domestic rats (\(N = 10\)) and expected an even sex ratio, we would expect five individuals to be female and five to be male (there are two categories for gender, \(10/2 = 5\))

b. Determine the observed frequency for each event by examining the original data.

   For example, for our sample of ten domestic rats, determine the actual gender of each individual

   Let us say that in our actual sample there are two male and eight female domestic rats
c. Compare the observed and expected frequencies for each event using the $X^2$ statistic:

$$X^2 = \sum (o_i - e_i)^2 / e_i$$

where:

$o_i =$ the number of observations in a given category  
$e_i =$ the number of observations expected to be in a given category under random conditions

For example, based on our gender ratio data for ten domestic rats:

$$X^2 = ((2 - 5)^2 / 5) + ((8 - 5)^2 / 5))$$

$$X^2 = (9/5) + (9/5)$$

$$X^2 = 3.6$$

d. Determine the degrees of freedom associated with your study. The degrees of freedom are based on the number of categories observations may fit into ($C$). The formula for calculating the degrees of freedom is simply $C - 1$.

In our domestic rat gender example, we have one degree of freedom (two categories minus one equals one degree of freedom).

e. Compare the chi square result you calculated to critical values listed in a statistical text (a table of critical values is provided below as Table 1). To use the table, look at the critical value ($X^2$) next to the degrees of freedom that your study had. If your calculated $X^2$ value exceeds the critical value on the table, you can conclude that the observed distribution is statistically different than expected. More specifically, common statistical tables (e.g., Table 1) have critical values that indicate the level at which higher values have a 95% chance of being an actual difference (rather than a difference due to bias in your sample). In other words, the probability ($P$) of a higher value being due to biased sampling is 5%. This 5% standard is widely regarded as representing a low-enough chance of bias that the researcher can be confident her results are valid. Note the 5% standard scientifically as a ratio rather than a percent. Critical values on the chi square table indicate a probability of 0.05 ($P = 0.05$; this is the ratio that equals 5%). Thus, values higher than critical values have a probability less than 0.05 ($P < 0.05$).

In our domestic rat gender example, the critical value for a study with one degree of freedom is 3.8. Our calculated value was 3.6. Thus, we conclude that it is not possible to say that there is less than a 5% chance that the gender distribution we observed was different than that we expected ($P > 0.05$). What aspect of the data we collected accounts for our not generating a statistically significant result? Why do critical values for the chi square increase as degrees of freedom increase?
Table 1. Chi square ($X^2$) table showing critical values ($X^2$) for the chi square test at a level where $P = 0.05$. Degrees of freedom = $DF$.

<table>
<thead>
<tr>
<th>$DF$</th>
<th>$X^2$</th>
<th>$DF$</th>
<th>$X^2$</th>
<th>$DF$</th>
<th>$X^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.8</td>
<td>16</td>
<td>26.3</td>
<td>35</td>
<td>49.8</td>
</tr>
<tr>
<td>2</td>
<td>6.0</td>
<td>17</td>
<td>27.6</td>
<td>40</td>
<td>55.8</td>
</tr>
<tr>
<td>3</td>
<td>7.8</td>
<td>18</td>
<td>28.9</td>
<td>45</td>
<td>61.7</td>
</tr>
<tr>
<td>4</td>
<td>9.5</td>
<td>19</td>
<td>30.1</td>
<td>50</td>
<td>67.5</td>
</tr>
<tr>
<td>5</td>
<td>11.1</td>
<td>20</td>
<td>31.4</td>
<td>55</td>
<td>73.3</td>
</tr>
<tr>
<td>6</td>
<td>12.6</td>
<td>21</td>
<td>32.7</td>
<td>60</td>
<td>79.1</td>
</tr>
<tr>
<td>7</td>
<td>14.1</td>
<td>22</td>
<td>33.9</td>
<td>65</td>
<td>84.8</td>
</tr>
<tr>
<td>8</td>
<td>15.5</td>
<td>23</td>
<td>35.2</td>
<td>70</td>
<td>90.5</td>
</tr>
<tr>
<td>9</td>
<td>16.9</td>
<td>24</td>
<td>36.4</td>
<td>75</td>
<td>96.2</td>
</tr>
<tr>
<td>10</td>
<td>18.3</td>
<td>25</td>
<td>37.6</td>
<td>80</td>
<td>101.9</td>
</tr>
<tr>
<td>11</td>
<td>19.7</td>
<td>26</td>
<td>38.9</td>
<td>85</td>
<td>107.5</td>
</tr>
<tr>
<td>12</td>
<td>21.0</td>
<td>27</td>
<td>40.1</td>
<td>90</td>
<td>113.2</td>
</tr>
<tr>
<td>13</td>
<td>22.4</td>
<td>28</td>
<td>41.3</td>
<td>95</td>
<td>118.8</td>
</tr>
<tr>
<td>14</td>
<td>21.7</td>
<td>29</td>
<td>42.6</td>
<td>100</td>
<td>124.3</td>
</tr>
<tr>
<td>15</td>
<td>25.0</td>
<td>30</td>
<td>43.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rationale

The rationale of the chi-square analysis can best be understood by inspection of the chi square formula, which sums the squared differences between what was observed and what was expected, divided by the size of the expected. This means that the test statistic will be smaller when observed and expected values are similar and larger when they are different. The actual size of the calculated $X^2$ is also affected by the number of observed-expected comparisons, hence tabulated critical values get bigger as degrees of freedom increase. Nevertheless, for a given degree of freedom, larger calculated values indicate a decreased likelihood that the observed distribution is identical to the expected distribution.

Notice that values that comprise a calculated $X^2$ are divided by the number of expected observations. Thus, small expected quantities increase the $X^2$ result even if the actual difference between observed and expected observations is relatively small. To avoid this inflation, expected values must be relatively high. This is partly controlled by the relation between the number of categories to be studied and the sample size. The more categories to be studied, the large the sample size (number of observations) should be. A general convention is that all expected values in a given study must be greater than or equal to five. Note there is no minimum number of observed values per category (zero is fine).
EXAMPLE CHI SQUARE ANALYSIS

Honeybees (*Apis mellifera*) were allowed to forage at four different colors of artificial flowers. The number of bees at each flower 30 min after their release was counted. The data are summarized below:

<table>
<thead>
<tr>
<th>Flower color</th>
<th>Number of honeybees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>140</td>
</tr>
<tr>
<td>Green</td>
<td>25</td>
</tr>
<tr>
<td>Red</td>
<td>27</td>
</tr>
<tr>
<td>Yellow</td>
<td>27</td>
</tr>
</tbody>
</table>

To test the null hypothesis that honeybees visit flowers randomly, regardless of color, calculate the expected numbers of bees per flower color and use the $\chi^2$ test to determine whether actual observations were likely to have been different from those expected at random.

The total number of honeybee observations ($N$) was 219, and the number of categories ($C$, flower colors) was 4. Thus, the number of observations expected to occur if each flower type is visited equally is 54.75 ($219/4$).

Thus, the chi square calculation proceeds as follows:

$$
\chi^2 = \frac{(140 - 54.75)^2}{54.75} + \frac{(25 - 54.75)^2}{54.75} + \frac{(27 - 54.75)^2}{54.75} + \frac{(27 - 54.75)^2}{54.75}
$$

$$
\chi^2 = 177.0
$$

$$
DF = (4 - 1) = 3
$$

Our calculated chi square value (177.0) exceeds the critical value on the chi square table for 3 degrees of freedom (7.83), so we conclude that flower choice was not random and that honeybees preferred to visit flowers of a certain color. In a publication, these data would be reported in the following manner:

“Honeybees did not forage equally among flower colors ($\chi^2 = 177, df = 3, P < 0.05$)”, where $\chi^2$ = the calculated $\chi^2$ value; $df$ = degrees of freedom, and $P$ = the probability value (traditionally set at 0.05).

Which color of flower was preferred?
APPENDIX IV – PRIMARY LITERATURE

Primary (1ˢᵗ) literature: a primary research article is one that presents new data collected by the authors. Primary literature is fundamental to scientific research because all new findings are presented in this way. Thus, primary literature serves as the basic source of scientific knowledge. Use of primary literature is emphasized in this course. You will be required to use at least two primary sources in each lab report. Easy ways to recognize primary literature include presentation of new data for the first time and presence of methods and results sections (this is where the procedures and findings of the research are presented). Be sure you can recognize a primary literature source.

Other types of literature include secondary (2ⁿᵈ) sources such as literature reviews and textbooks and tertiary (3ʳᵈ) sources such as encyclopedias and dictionaries. Secondary sources cite other works, such as primary literature. They may derive new conclusions, but these would be based on the previous works. Secondary sources will not normally have a methods or results section and if data are presented in tables or figures, the sources of the data are cited because they are not the original work of the authors. Many review articles are specifically labeled as such. Tertiary sources summarize general knowledge and only in special cases cite other works. They never derive or present new conclusions.

Finding primary literature: your best source for primary literature is the Weber State University Stewart Library. Many scientific journals are available in hard copy in the library and electronically through the library web site. You can also search a variety of article databases through the Stewart Library web site. Some articles you find will be available on campus or electronically, others will be unavailable because they are in journals the Stewart Library does not subscribe to. However, the Stewart Library makes available articles that are not immediately available on campus or electronically via the inter-library loan system. Thus, virtually any article that exists is available to you!

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OTHER ARTICLE DATABASES:
Aside from searching via Google Scholar, you can find articles immediately available (for free) through article databases subscribed to by Weber State University. These include:

1. BioOne;
2. JSTOR;
3. Wiley Online Library.

SCIENCE LIBRARIAN:
If you are still having problems finding articles, you may wish to contact the science librarian JaNae Kinikin (626-6093; JKINIKIN@weber.edu) who can assist you with literature search and with tips for finding relevant journal articles.
**COPIES OF PRIMARY LITERATURE FOR LAB REPORTS:**

When you print or photocopy primary literature sources to turn in with your lab report, make sure they are in the same format as they are found in the actual journal (i.e., hard-copy). Some internet sources provide journal articles in “.html” format, in which the text is separate from the tables and figures and the text conforms to your computer screen or dialog box. Do not print this format. To be sure you have the proper format either print the “.pdf” file, which contains the journal article in its official form, or find the article in hard copy in the Stewart Library and make a photocopy. Each article you submit should be stapled separately. It is ok to print the article double-sided or with more than one page per printed page (to save paper and printing costs) so long as all text is readable to the naked eye.
In-text citations for literature:
In scientific writing, sources of supporting information must be acknowledged. Further, it is only appropriate to cite papers you have read. It is inappropriate to cite papers based on another citation because other authors may misuse or misinterpret the paper you wish to cite or they may incorrectly report the literature citation. You will perpetuate such mistakes unless you read the paper yourself and compile your own original and accurate literature citation. However, use of direct quotations is avoided. Rather, it is conventional to paraphrase findings of relevant sources in a manner consistent with the source being cited but also relevant to the subject at hand. Cite references as support for summary statements you provide in text. Such statements should be written in a manner that stands alone. That is, readers should be able to understand your meaning based solely on the text you present. However, readers that desire additional detail can refer to the sources you cite. Appropriate sources to cite are generally published works that can be found in a library such as journal articles, books, and book chapters. Primary research is almost always presented in journal articles (Appendix IV). Other works, such as web sites, are not generally cited because they are not reliable (they may be here today but gone tomorrow). Also, information presented in a web site rarely receives much scrutiny before publication compared with books or journal articles. Thus, information presented in web sites is much more likely to be inaccurate or biased.

The citation format you will use for your lab reports is a basic “author-year” format that includes only the last name of the author and the year of publication. If two authors wrote a paper you are citing, provide the last names of both authors separated by the word “and” (not an ampersand). If three or more authors wrote a paper you are citing, provide the last name of the first author and use the Latin phrase “et al.” to indicate additional authors (however, all the authors are listed in the Literature Cited section). Et al. stands for et alia, translated as “and the rest”, so there is no period after et (this is the full word) but there is period after al. (this is an abbreviation). Because this phrase is literally interpreted as “the first author and the rest of the authors”, there is no comma between the last name of the first author and et al. Also, you will see in some journals that “et al.” is presented in italics, but do not use that format for your lab reports (follow instructions and examples here). Do not change the order of authorship! This order is determined by the authors themselves and represents the relative contributions of each individual involved. In the format used here, authors should never be separated by a comma, but a comma is used to separate the author names from the year of publication. The year of publication is the copyright year (some articles give other years, such as the year an article was first submitted, but this year has no significance for citation). Each time an article is cited, the full citation must be given. It is also possible to give the author names in text as part of a sentence, in which case the year of publication is always provided immediately after the author names. Below are some examples of citations following acceptable formats for your lab reports.

In-text citation examples for literature:
1. Standard format with statement attributable to findings reported in a specific source:
   a. Single author citation:
      i. “Predicted climate change in New Zealand is likely to combine with expanding dairy farms to further endanger native freshwater fishes (Ling, 2010).”
   
   b. Dual-author citation:
      i. “Diet overlap does not always indicate competition among species (Hlohowskyj and White, 1983).”
c. Three or more author citation:
   i. “The distribution of brown trout (*Salmo trutta*) in streams along the Wasatch Front
      is limited by stream size and associated instream habitat availability (Giddings et
      al., 2006).”

**Literature Cited:**
The literature cited section of your lab report must contain all of the literature you reference (i.e., cite). Similarly, no reference can appear in this section that is not cited somewhere in your report. References are ordered alphabetically by the last name of the first author. Do not change the order of authorship! The format for the Literature Cited section must be consistent among all citations in your lab report. Follow the format indicated in the examples below closely in every single detail. Note the second line (and following lines) is indented (hanging indent). Although some journals allow journal titles to be abbreviated, you should write out the full journal name for your lab reports. Make sure you cite the volume and page numbers correctly. For citing books, the style is a bit different. Instead of the journal name and volume, the publisher and city of publication are provided. Note that only the first word and proper nouns are capitalized in journal article titles, whereas all major words are capitalized in journal titles and book titles. You will see in some journals that various portions of citations are italicized (e.g., journal titles) but for your lab reports do not italicize any words except scientific names (when present). All text in your lab report should be double spaced, including literature cited. The literature cited section does not need to be on a separate page from the main text. Simply leave a space between your text and the title for the Literature Cited section.

**Examples of literature cited formats for different, appropriate sources:**

**Journal article format:**

*Single author article:*


*Dual author article:*


*Three or more author article:*


**Book format:**

**In-text citations for figures:**
Figures illustrating your study materials or data must be cited in your Materials and Methods or Results section to direct readers to them at the appropriate time. Figures should present information relevant to your study goals in a manner intended to clearly inform readers. As with citations involving literature (described above), you will cite your figures as support for summary statements you provide in text. Such statements should be written in a manner that stands alone. That is, readers should be able to understand your meaning based solely on the text you present. However, readers that desire additional detail can refer to the figures you cite.

**Example of the figure cited format for lab reports (refers to Figure 1 in Appendix II, assume the scientific name has been given previously):**
1. “Domestic rats fed the experimental diet grew faster than those on the standard (control) diet (Fig. 1).”

**In-text citations for statistical results:**
Statistical results of your study are also presented as citations that support summary statements you make to inform readers of your findings. In this case, pertinent statistical information is provided in parentheses. Symbols that are abbreviations for statistical parameters are always presented in italics, but mathematical symbols (such as the equal sign or less-than sign below) and numerals are presented in standard (normal) font.

**Example of statistics cited format for lab reports (refers to example chi square analysis in Appendix III):**
1. “Honeybees did not forage equally among flower colors ($X^2 = 177, df = 3, P < 0.05$).”
RUBRIC FOR PRINCIPLES OF ZOOLOGY II LAB REPORTS

Overall Paper = 14
___Title < 20 words, descriptive, includes dependent and independent variables of study 0 1 2
___Scientific and common names correctly represented in text and figure captions (italics, capitalization) and given on first use only for all species mentioned 0 1 2
___No spelling errors, contractions, errors in grammar or punctuation, good readability, use past tense for completed actions, refer to yourself as sole author (I not we) 0 1 2
___Science formatting correct, proper abbreviations used (do not start a sentence with an abbreviation), superscripts and subscripts used when appropriate, all measures metric (not English) 0 1 2
___*Correct manuscript format, including: (1) title page, (2) all text double-spaced, (3) all pages single sided, (4) all text in a single column, (5) tables and figures (if included) at end of manuscript (after Literature Cited), (6) all pages numbered at bottom center, (7) font type and size consistent throughout: 0 1 2 3 4
___Proper scientific organization: each section is discreet and includes only appropriate information (follow organization indicated below by section) 0 1 2

Introduction = 8
___*Background information provides context. Appropriate references used with relevant findings summarized/paraphrased (not quoted): 1 2 3 4
___*Goals of study clearly presented with hypothesis or predictions: 1 2 3 4

Materials and Methods = 6
___*Data collection procedures clearly described with proper illustration and citation of any elaborate apparatus (features of illustrations not repeated verbatim in text): 1 2 3 4
___Procedures for data analyses (data manipulation and presentation) described clearly, but without unnecessary detail 0 1 2

Results = 8
___*Results summarized without unnecessary detail (do not repeat figures or tables verbatim) and focused on study goals, hypotheses, or predictions. Figures cited as support for summary statements in text using correct format and proper sequence: 1 2 3 4
___*Figures, tables, and results of data analyses (e.g. statistical tests) presented in correct format and correctly calculated: 1 2 3 4

Discussion = 8
___*States hypothesis was correctly accepted or rejected with supporting rationale. Appropriate references used with relevant findings summarized/paraphrased (not quoted): 1 2 3 4
___*Results interpreted (but not repeated) in light of other studies: 1 2 3 4

In-text citations & Literature Cited = 6
___Proper in-text citation style and all references cited 0 1 2
___Proper Literature Cited format and all citations referenced 0 1 2
___Correct number and type of references (two 1° references) included in “.pdf” format 0 1 2
RUBRIC FOR PRINCIPLES OF ZOOLOGY II LAB REPORTS

Overall Paper = 14
___Title < 20 words, descriptive, includes dependent and independent variables of study 0 1 2
___Scientific and common names correctly represented in text and figure captions (italics, capitalization) and given on first use only for all species mentioned 0 1 2
___No spelling errors, contractions, errors in grammar or punctuation, good readability, use past tense for completed actions, refer to yourself as sole author (I not we) 0 1 2
___Science formatting correct, proper abbreviations used (do not start a sentence with an abbreviation), superscripts and subscripts used when appropriate, all measures metric (not English) 0 1 2
___*Correct manuscript format, including: (1) title page, (2) all text double-spaced, (3) all pages single sided, (4) all text in a single column, (5) tables and figures (if included) at end of manuscript (after Literature Cited), (6) all pages numbered at bottom center, (7) font type and size consistent throughout: 0 1 2 3 4
___Proper scientific organization: each section is discreet and includes only appropriate information (follow organization indicated below by section) 0 1 2

Introduction = 8
___*Background information provides context. Appropriate references used with relevant findings summarized/paraphrased (not quoted): 1 2 3 4
___*Goals of study clearly presented with hypothesis or predictions: 1 2 3 4

Materials and Methods = 6
___*Data collection procedures clearly described with proper illustration and citation of any elaborate apparatus (features of illustrations not repeated verbatim in text): 1 2 3 4
___Procedures for data analyses (data manipulation and presentation) described clearly, but without unnecessary detail 0 1 2

Results = 8
___*Results summarized without unnecessary detail (do not repeat figures or tables verbatim) and focused on study goals, hypotheses, or predictions. Figures cited as support for summary statements in text using correct format and proper sequence: 1 2 3 4
___*Figures, tables, and results of data analyses (e.g. statistical tests) presented in correct format and correctly calculated: 1 2 3 4

Discussion = 8
___*States hypothesis was correctly accepted or rejected with supporting rationale. Appropriate references used with relevant findings summarized/paraphrased (not quoted): 1 2 3 4
___*Results interpreted (but not repeated) in light of other studies: 1 2 3 4

In-text citations & Literature Cited = 6
___Proper in-text citation style and all references cited 0 1 2
___Proper Literature Cited format and all citations referenced 0 1 2
___Correct number and type of references (two 1° references) included in “.pdf” format 0 1 2