Core Knowledge
Biology
Syllabus

About the course:

This course is designed to prepare teachers to teach biology in elementary schools and middle schools, especially, though by no means exclusively, in schools using the Core Knowledge curriculum. Some areas of biological sciences are emphasized because they are taught in greater depth to elementary school children. The course is designed to be implemented in a thirteen-week semester, with two lecture hours per week and one three-hour lab session. Extensive reading assignments are necessary in order that teachers absorb the material and learn many of the background facts and concepts that cannot be presented comprehensively in lecture and lab.

College biology textbooks for non-majors typically start with a short exposition on chemistry and the structure of matter. The concepts of bonding and chemical energy are developed in order that students may better understand biochemical processes such as photosynthesis and glycolysis. Hydrogen bonding, pH, ionization, and the properties of water are also important "solution concepts" that will help students understand cell processes, such as DNA replication, and physiological systems such as digestion and nerve conduction.

Following the chemistry "refresher", most courses present the energetics of membrane transport, based on the compartments of eukaryotic cells, and then discuss the biochemical foundations of photosynthesis and glycolysis. Cell reproduction and the composition of chromosomes are presented next, with extensive discussion of DNA replication and gene expression. Meiosis in cells leads naturally to a discussion of Mendelian genetics, and phenotypes of whole organisms.

Classical genetics is typically presented as a basis for population dynamics, and the development of the subject relies on the concepts of genetic diversity and mutations, phenotype, and natural selection. Fossil evidence for evolution can also be introduced in this context, and Darwin's theory for the origin of species through natural selection is a natural synthesis of ideas. Taxonomy builds upon the idea of evolution, and students can see a progression of body complexity in animals as diverse as sponges, tapeworms and humans.

Plant and animal physiology usually follows from a discussion of phylogenetics, for with a foundation of "structure" the student can more readily appreciate "function." Some college textbooks present the physiology of animals first while others present the plants first. In plant physiology, the tissue types, tropism, nutrition, gas exchange, and transport systems are important points of discussion. In animal physiology, there several important body systems (circulatory, respiratory, digestive, excretory, immune, endocrine, nervous, reproductive, and musculoskeletal), and these may be linked together by an overall discussion of homeostasis. Developmental biology and embryology may be presented as an adjunct to the reproductive system, or it may be handled separately.

Ecology is often the "capstone" of the college biology course, because it brings together many elements from the subject. For example the knowledge of photosynthesis and glycolysis gained much earlier in the course helps students understand the flow of carbon in the environment. The knowledge of genetics and natural selection helps students understand the process of adaptation, and knowledge of physiology helps students understand why one phenotype might lend a selective advantage. Animal behavior is often taught in the context of ecology, though some textbooks treat it as a separate area. The concepts of producers and consumers, food chains and food webs in a habitat, and energy flow through an ecosystem are important, and the influences of humans and climate on an ecosystem are usually introduced in this context.

Elementary schools typically do not present the topics of biology in the same order as they would be presented in a college course, and there many good reasons for this. While young children can learn a little about the atom in the earliest grades, they will more readily learn concepts of ecology, or plant and animal form and function, than biochemistry and cellular biology. For young children, concrete issues may be more easily absorbed than abstract ones, but the same logic does not necessarily apply to their teachers. Teachers will be better equipped to explain even the most basic biological topics if they have mastered the abstract ideas taught in the first weeks of an undergraduate biology class. It is safe to assume that all undergraduates attended an elementary school in their youth and have already absorbed a wealth of natural experiences (and perhaps even knowledge) about plants and animals. Drawing upon their understanding of the broad outlines of biology, pre-service elementary school teachers are ready to enter into a logical development of the field, starting with biochemistry and ending with ecology. A broad array of textbooks teach the subject in this order, and nearly any one could substitute for the books that have been selected for this syllabus.

For the lecture component of the course we have selected *Biology Concepts and Connections*, by Neil A. Campbell, Lawrence G. Mitchell, and Jane B. Reece, 3rd edition., Benjamin Cummings Publishing Co., Menlo Park, CA, 2000. 809pp. ISBN: 0-

8053-6585-0. Another usable textbook is *Biology: Life on Earth*, by Teresa Audesirk, Gerald Audesirk, Bruce E. Byers, 6th edition, Prentice Hall, 2001. 892 pages ISBN: 0130899410. (For a chart of how the topics in Campbell, Mitchell and Reese collate with the topics in the text by Audesirk and Audesirk, see appendix B.)

For the Laboratory Component we have chosen *Encounters with Life: General Biology Laboratory Manual*, by Hans Fredrik Edward Wachtmeister, and Larry J. Scott, 5th Ed. Morton Publishing Co., Englewood CO, 1997. 366pp. ISBN: 0895823624

In the syllabus, the reader will find "CK Sequence links" listed. These refer to relevant sections in the *Core Knowledge Sequence: Content guidelines for grades K-8* (1999 edition*)*, published by Core Knowledge Foundation, Charlottesville, VA. (Available for purchase at www.coreknowledge.org) The notations provide a brief title and section name, for example "vascular plants [Gr.5§IIIA, p. 127]" indicates that readers can find this subject in the *Core Knowledge Sequence* in Grade 5 Science, section 3, subsection A, page 127. It is possible to teach the course without ever referring to the Core Knowledge Sequence, but some professors may find it useful to refer to these guidelines as they teach, as they give a clear indication of what elementary school teachers teaching the Core Knowledge curriculum will be asked to teach.

Use of this Syllabus:

This syllabus was created by Stan Metzenberg, Assistant Professor of Biology at California State University Northridge, as part of *What Elementary Teachers Need to Know*, a teacher education initiative developed by the Core Knowledge Foundation.. Although the syllabus is copyrighted by the foundation, and may not be marketed by third parties, anyone who wishes to use, reproduce, or adapt it for educational purposes is welcome to do so. However, we do ask individuals using this syllabus to notify us so we can assess the distribution and spread of the syllabi and serve as a repository of information about how they may be improved and more effectively used. Please contact Matthew Davis, Core Knowledge Foundation, 801 East High Street, Charlottesville, VA 22902. Phone: 434-977-7550, x. 224. E-mail: mdavis@coreknowledge.org

Lecture 1 - Welcome to the course

Objectives: Students are welcomed to the class, and the syllabus, course policies, and overall content are discussed.

CK Sequence links: Examples in this lecture are on the subjects of ecology [Gr.3§V, p. 83], the heart [Gr.4§IA, p. 104], genetic engineering [Gr.7§III, p.176], and the biography of scientist Ernest Just [Gr.5§VII, 129].

Important points:

- This course is specifically designed for K-8 teachers (in-service or pre-service), particularly those who will be using the Core Knowledge Foundation curriculum.
  A. Not every important aspect of biology can be taught in this short class, and the goal is to prepare the students to teach the basics of biology to elementary and middle school students.
  B. Attendance at all class sessions and laboratories is required, and the assigned readings are an essential element of the course.
  C. After completion of the course, and after the students become teachers, they should continue to read biology-related books and articles, to refresh their memories and maintain a high standard of scholarship.

Introduction to the field of biology

Three anecdotes are presented to introduce the field (The instructor may wish to substitute other examples that are similarly illustrative of the broad range of topics in biology).

1. (Ecology) One of the results of population growth and urban expansion has been the fragmentation of ecological habitats. In many areas there are small patches of habitat that are almost like oceanic islands, with limited species richness. Some biologists study the types of species that inhabit fragmented habitats, distinguishing between

"edge" and "interior" environments. The Gray catbird (Dumetella carolinensis) and American robin (Turdus migratorius), for example, are frequently are found in small forest patches while the ovenbird (Seiurus aurocapillus) and worm-eating warbler (Helmintheros vermivorus) inhabit older forest strands.[1] By improving our understanding of animal behavior and interrelationships, ecologists help to preserve the richness of species and the beauty of our environment.

2. (Physiology) Muscles in the body, including the heart, rely on electrochemical signals for contraction. The heart has its own built-in activator that acts independently of the central nervous system and controls the rhythm of the heartbeat. This natural pacemaker of the heart can sometimes fail or become erratic, and scientists have developed artificial pacemakers that can deliver electrical impulses to the region. Physiologists study how organs work, and this knowledge helps to extend and improve the quality of our lives.

3. (Molecular biology) Seventy percent of children under the age of five in Southeast Asia suffer from vitamin A deficiency. Molecular biologists have made a genetically engineered rice strain that produces beta-carotene, the precursor of vitamin A that is commonly found in carrots.[2] It is hoped that this new strain (called Golden Rice because of its yellow-orange color) will help to alleviate vitamin A deficiency, and considering that rice is a staple for half of the world's population this may be a realistic goal. Molecular biologists and biochemists study the molecules that make up living organisms, and this is an example of the type of benefit this knowledge can bring.

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[1] Smith, Robert L. and Thomas M. Smith. Elements of Ecology, 4th Ed. Addison Wesley Longman, Inc., San Francisco, 2000. pp. 285-287

[2] Guerinot, Mary Lou. " Enhanced: The Green Revolution Strikes Gold " Science 287: 241-243 (2000)

The scientific method

Science is a body of facts and knowledge, and also a method for extending our knowledge through experiment. One course goal is to provide students with the foundation of facts and knowledge that will make them competent teachers. Another goal is to make the students knowledgeable about how science is performed in the laboratory and field.

Scientists do not start their life's work "from scratch," knowing only what they have seen with their own eyes. They learn from each other, and they expand upon what is already known. In order that students may better understand the scientists who have developed the field of biology, biographical sketches of notable scientists will be introduced from time to time in the course. For example:

A. Ernest Just, a marine biologist and leading African-American scientist of the 20th century[3], did pioneering work on fertilization in marine invertebrates, publishing fifty papers.

The reading assignment

The course will begin at the next lecture with a discussion of the structure and function of cells. Students should read Chapter 4 in Campbell, Mitchell and Reece, pp. 50-68, and study the Chapter Review on pp. 68-69. This being the first reading assignment of the course, the importance of being prepared and attending lectures should be reiterated.

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[3] Manning, Kenneth R. "Black Apollo of Science : The Life of Ernest Everett Just". Oxford University Press. 1984.

Lecture 2 - Tour of the cell

Advance reading: Chapter 4, Campbell, Mitchell and Reece, pp. 50-69.

Objectives: In this lecture, students learn or review the fundamentals of cell biology.[4] The functions of mitochondria and chloroplasts, and the molecular basis of heredity and gene expression will be discussed in more detail later in the course.

CK Sequence links: Cells[Gr.2§IIIA, p. 60; Gr.5§II, p. 127]

The size and structure of a cell

Students learn that the cell is the smallest unit of life. All life is composed of cells that have come from other cells (The Cell Theory). It might be appropriate to mention that some ideas that are called "theories" in science are actually so well established that there is no doubt as to their validity.

- The scale of a bacterium and its structural simplicity is illustrated, touching on the fact that it contains a DNA chromosome (containing genes), plasma membrane, and cell wall.
- The scale of a eukaryotic cell and its compartmentalization (nucleus and cytoplasm) is discussed. The eukaryotic cell has a cytoskeleton that permits it to adopt a wide variety of shapes (a neuron looks much different from a white blood cell, thanks to the cytoskeleton).

Eukaryotic cells have organelles that perform specific functions, such as mitochondria (harvesting chemical energy), chloroplasts (capturing solar energy), lysosomes (digestive functions), endoplasmic reticulum and Golgi apparatus (protein transport and

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[4]Note to instructor: There is not sufficient time in this course to cover the preparatory chapters in chemistry, hence the molecular foundation of cellular biology will not have been laid for the student. Where appropriate, it may be necessary to supplement the cellular biology with critical points that were omitted from the readings.

secretion). Mitochondria and chloroplasts are related to bacteria and carry their own set of genes.

The nucleus of the eukaryotic cell houses most of the cell's DNA, organized into units called chromosomes. Human cells for example, typically contain 46 chromosomes. DNA is the repository of genetic information, and it contains coded instructions for how specific cellular proteins are constructed from amino acid precursors.

All animal, plant, and fungal cells are eukaryotic. In addition, there are many single-celled eukaryotic organisms called protists that include amoebae, ciliates, and flagellates. Some protists can perform photosynthesis (autotrophic), while others live by consuming bacteria or other protists (heterotrophic). The latter are often called protozoans. Plant cells have cell walls based on the molecule cellulose. Animal cells do not have cell walls, nor do they have chloroplasts. Fungal cells have cell walls that are based on chitin, the same molecule found in crab shells.

Cilia and flagella in eukaryotes are based on cytoskeletal components and are used for some kinds of cell movement. The protozoan *Paramecium* for example, is covered with cilia that beat in a pulsed wave. Some cells in the airways of the human lung have cilia for a purpose other than cell movement - the cells are fixed and use cilia to move mucus up to the pharynx, where it can be swallowed. Flagella are related to cilia in structure, and many protists (such as *Euglena*) use a flagellum or flagella for movement. Human sperm have flagella that are used during movement into the uterus and fallopian tubes.

The reading assignment

The next lecture will be a discussion of some of the molecular-scale aspects of the cell, including the role of enzymes. Chapter 5 in Campbell, Mitchell and Reece, pp. 70-87.

Laboratory 1 - Microscope lab

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual,* 5th Edition. pp. 1-12

Objectives: In this laboratory, students learn how to set up and use microscopes to observe cells, both living and fixed. They develop a sense of scale at the cellular level.

CK Sequence Links: Cells [Gr.2. §IIA, p. 60; Gr.5§II, p. 127], vascular plants [Gr.5§IIIA, p. 127].

Outline- topics for discussion in the first laboratory period

I. Laboratory safety and course policies

II. The parts of a microscope, and their proper use. (eyepiece, ocular lens, objective lens, specimen stage, condenser lens, light source). Adjustment of coarse and fine focus knobs, condenser position, and light source.

III. How to keep a laboratory notebook, recording materials and methods, and observations.

IV. Magnification - test focus on letters printed on paper, to develop a sense of magnification. The resolving power of light and electron microscopes at high magnifications should be discussed, and the arithmetic meaning of magnification powers should be illustrated.

V. Plant cells. Celery sections can be prepared by students using a single-edged razor blade, and the celery can be pre-stained to highlight the xylem. Cork sections (the original Hooke experiment by which the word "cell" was applied) may also be of interest.

VI. Animal cells. Fixed and stained sections of animal tissues can be obtained from biological supply houses. For example, early-stage chick embryo sections can be used to show brain, heart, and skeletal development, and to link the idea of cell and tissue and whole organism.

VII. Protists. A hay infusion can be prepared some days in advance (this will need to be tested by the instructor in advance of the lab) to show living and moving protozoans. Students can sample the water from different parts of the broth (e.g. near the surface or near the bottom) and find different species present. While the detailed structures of moving protozoans are difficult to discern (unless agents are applied to slow down their movement) their speed in a microscope field is sure to impress.

Student observations of sections of vascular plants and live protists should be recorded in their laboratory composition notebooks. A laboratory report based on these methods and observations should be submitted within one week.

Lecture 3 - Energy, entropy, and cellular processes

Advance reading: Chapter 5, Campbell, Mitchell and Reece, pp. 70-87.

Objectives: In this lecture, students learn or review the fundamentals of energetics in reactions, which is necessary for understanding of nutrition, cellular respiration, photosynthesis, and enzyme action.

CK Sequence links: Cell structures and processes [Gr.5§II, p. 127]

Energetics and basic physical chemistry

Students should learn the definitions of the words "energy" and "work" and "entropy," using the formal meanings applied by physicists. They should learn about the law of conservation of energy (First Law of Thermodynamics). In a closed system, the total energy E is constant and is accounted for by the equation $E=q+w$, where q is the heat added to the system and w is the work done on the system.

Energy can harnessed to do useful work, but a portion of the energy is wasted as thermal energy or an increase in entropy (Second Law of Thermodynamics). This may be best illustrated by use of a modified version of the Gibbs Free Energy equation: $\Delta H = \Delta G + T\Delta S$. That is, the change in chemical bond energy (ΔH) is a mixture of energy that can be used (ΔG) and energy that is wasted by increasing disorder ($T\Delta S$) in the system. Where the change in energy in a reaction is less than the amount of energy lost to disorder ($\Delta H<T\Delta S$), the reaction proceeds "spontaneously" and produces heat (exergonic). Where the opposite is true ($\Delta H>T\Delta S$) the reaction does not proceed spontaneously and absorbs heat (endergonic). These statements refer to the average or net behavior of the molecules in a system -- not the behavior of individual molecules.

A reaction or process can be driven by entropy (an example being passive transport) and many chemical reactions in a cell are driven in a forward direction because of the increase in disorder they bring. Students should learn the meaning of the terms "activation barrier" and "net change in energy" for a reaction. Enzymes are catalysts that can lower the activation barrier of a reaction and increase the rate of favorable (spontaneous) reactions. They cannot alter the net change in energy, and so they cannot turn an unfavorable reaction into a favorable or spontaneous one.

A reaction that is "unfavorable" or "non-spontaneous" can be tied to a concomitant reaction that is favorable - that is why ATP is useful as an energy currency. The reaction ATP -> ADP + Pi is highly favorable, and enzymes can tie forward progress of unfavorable reactions (for example active transport against a concentration gradient) to ATP hydrolysis. As an analogy, water can be moved uphill (unfavorable) by tying its transport to the burning of gasoline (favorable) in a motor-driven pump.

Cellular energetics - overview

- Chloroplasts capture sunlight energy, storing it in chemical bonds.
- Mitochondria are sites of cellular respiration, and can make available large amounts of chemical bond energy from food.

The functions of these important organelles will be discussed in the next two lectures. While these functions are being discussed at a molecular level, students should keep in their mind the overall model for energy flow in the environment. Plants (and photosynthetic protists and cyanobacteria) are primary producers and the point of entry of energy in a food chain. Consumers (such as humans) extract energy from other organisms (i.e. "food").

The reading assignment

The next lecture will cover cellular respiration - the function of the mitochondria. Students will prepare themselves by reading Chapter 6 in Campbell, Mitchell and Reece, pp. 88-107.

Lecture 4 - Cellular respiration

Advance reading: Chapter 6, Campbell, Mitchell and Reece, pp. 88-107.

Objectives: In this lecture, students learn or review the function of cellular respiration. They learn that plant and animal cells use oxygen to break down macromolecules into carbon dioxide and water, extracting useful energy. They learn that in animals, macromolecules are made from other macromolecular precursors - not from elements or even carbon dioxide.

CK Sequence links: Cell structures and processes [Gr.5§II, 127], chemistry of food and respiration [Gr.8§V, 201]

The structure and function of the mitochondrion

The following may be useful as discussion points:

- Aerobic and anaerobic environments. Fermentation in yeast, and lactic acid production in anaerobic exercise. Initiation of glycolysis in the cytoplasm.
- The role of the heart and lungs in supplying oxygenated blood, and the difference between the terms respiration (as in "breathing") and respiration (as in oxygen use by a cell).

The mitochondrion has an outer membrane and an inner membrane, the latter of which is formed into folds that are called cristae. A group of biochemical reactions that constitute the Krebs cycle take place within the lumen of the inner membrane, and the ATP synthase enzyme that generates ATP from ADP and phosphate is embedded on the lumen-side of the inner membrane.

Molecules of glucose are degraded from 6-carbon units to 3-carbon units in the cytoplasm. Some of these may be degraded to ethanol (in yeast) or lactic acid (in our muscles), but efficient harvesting of energy requires transferring the 3-carbon units (pyruvic acid) to the mitochondria for catabolism. The pyruvic acid is broken down into a 2-carbon unit (acetyl-), which is added to a carrier molecule (CoA), and one carbon dioxide molecule is generated as well. The 2-carbon unit is fused with a 4-carbon molecule to make a 6-carbon unit, and during one "turn" of the cycle two carbon dioxide molecules are generated and the 4-carbon carrier molecule is regenerated (i.e. made ready for the next 2-carbon unit).

By this biochemical loop, the carbon atoms from the sugar are entirely converted to carbon dioxide. Energy (in the form of several ATP molecules generated from ADP and phosphate), and high-energy electrons (in the form of $FADH_2$ and NADH) are the "payout" of the cycle. The real prize however, is the high-energy electrons in $FADH_2$ and NADH that are introduced into the electron transport chain embedded in the inner mitochondrial membrane. As these electrons are passed from molecule to molecule in the chain, part of their energy is extracted and used to pump protons from the lumen of the mitochondria into the intermembrane space. This creates a concentration gradient of protons that can be harvested (by ATP synthase) to drive the reaction ADP + Pi -> ATP. A concentration gradient is a form of potential energy, just like a compressed spring, and can be used to do useful work. In this case, the useful work is to make ATP molecules that are a common "energy currency" for the cell. Approximately seventeen times as many ATP molecules are generated from the electron transport chain and ATP synthase as are generated by the Krebs cycle by itself, or the cytoplasmic steps of glycolysis. The ratio of concentration of ATP to ADP is kept very high by the mitochondria. The phosphate bond in ATP is said to be "high energy" and this is in part because the reverse reaction is unlikely (there being little ADP on hand). Many cellular enzymes break down ATP to ADP, cashing in on some of this stored energy and using it to drive forward unfavorable reactions.

The reading assignment

The next lecture will cover photosynthesis - the function of the chloroplast. Students will prepare themselves by reading Chapter 7 in Campbell, Mitchell and Reece, pp. 108-124, including the Chapter Review.

Laboratory 2 – Cell structure

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual*, 5th Edition. pp. 19-24

Objectives: In this laboratory, students learn how to distinguish between types of cells (prokaryotic, eukaryotic, plant, and animal), and learn the structures and functions of cell organelles.

CK Sequence Links: Cell strutures and processes [Gr.5§II, p. 127], vascular plants [Gr.5§IIIA, p. 127], human body cells [Gr.2§IIIA, p. 60].

In this laboratory, students use a microscope to study a variety of types of cells on slides. Using a figure in the laboratory manual as a guide, they will be able to observe the relative sizes of cell and nucleus, and learn about numerous organelles that are too small to discern by light microscopy. While learning the structures, they will also learn the specific functions associated with each organelle.

Outline- Types of cells studied in this laboratory exercise:

I. Plants
   A. Elodea leaf
   B. Onion Leaf Epidermis
   C. Cells of the potato

II. Animals
   A. Human cheek cells
   B. Human blood smear

III. Prokaryotic cells

A. Cyanobacteria

Lecture 5 - Photosynthesis

Advance reading: Chapter 7, Campbell, Mitchell and Reece, pp. 108-124.

Objectives: In this lecture students learn that most plants are autotrophic, obtaining their energy from the sun. They learn that in the process of photosynthesis, carbon dioxide from the air or water and the energy from sunlight is used to generate "fixed" carbon compounds such as sugars, from which other biological macromolecules are made.

CK Sequence links: Plant Structures and Processes. Photosynthesis [Gr.5§IIIB, p. 127]

An historical perspective and the scientific method

This is an opportunity to discuss the scientific method, and the experiments that led to our current understanding of photosynthesis. It used to be believed that plants obtained their mass from soil constituents, but the Belgian scientist van Helmont disproved this hypothesis. He planted a willow tree in a pot and after a long period of growth separated the soil and plant, determining that the soil had not lost a significant amount of mass compared to the increase in tree mass. We now know that the carbon atoms in a plant, which are a good proportion of the total mass, are derived entirely from carbon dioxide in the air.

Overview of photosynthesis

Because plants produce the "fixed" carbon molecules that enter the food web, they are usually referred to as primary producers. As will be discussed later in the course, nearly all life on earth[5] depends on matter and energy introduced into the ecosystem by plants and other photosynthetic organisms such as cyanobacteria and autotrophic protists[6].

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[5] A notable exception being chemolithotrophic bacteria.

[6] Cyanobacteria were formerly called "blue green algae" and are prokaryotic rather than eukaryotic. Autotrophic protists are single-celled eukaryotic organisms that carry chloroplasts, such as Euglena, or

To fully understand photosynthesis, it is important to consider the roles of plant tissues (such as leaf stomata), subcellular structures (such as chloroplasts), and molecules (such as chlorophyll). Stomata can be seen on the underside of some leaves, using a hand lens or microscope. These are the "ports" through which carbon dioxide from the air is able to enter the tissue space within the leaf. Some plants need to regulate the time of day that these stomata are open, since the time of highest solar intensity is also a time when a plant can lose a great deal of water vapor through the stomata.

Chloroplasts are organelles, and it is interesting to note that they carry a DNA genome of their own because they are descendents of free-living cyanobacteria. The inner membrane of the chloroplasts houses the compartment called the stroma, where the synthesis of sugars takes place. The stroma also contains thylakoids, which are made up of stacks of membranous sacs called grana.

Suspended within the thylakoid membrane are the light-reactive centers containing chlorophyll, and the electron chains that establish a proton gradient. This is analogous to a process already discussed in mitochondria during oxidative phosphorylation, however in chloroplasts the proton gradient is established across the thylakoid membrane. There are two types of photosystems or reactive centers containing chlorophyll, and they respond to slightly different colors of light.

On the surface of the grana (the thylakoid membrane), sunlight causes electrons in the photosystem to become energized, and this energy is used to pump protons into the grana and reduce $NADP^+$ to NADPH. The source of these electrons at the photosystem is H_2O, which during the course of being split apart liberates O_2 gas. The protons pumped into the grana exit through an ATP synthetase enzyme. This enzyme uses the

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colonizing protists such as Volvox. In older texts, these were classified as plants, but now they are recognized as being distinct.

energy of the proton concentration gradient to generate ATP, a high energy phosphate bond, from ADP and phosphate.

Two "outputs" from the light reaction, the ATP and NADPH, are important "inputs" for the dark reaction. Carbon dioxide is an oxygen-rich form of carbon, and the process of fixation into sugars involves "reducing" that level of oxidation by addition of electrons. NADPH carries electrons and contributes them to the photosynthesis reaction, being converted back to NADP+ in the process. The conversion of ATP to ADP is an extremely favorable reaction, and is used to drive an unfavorable one (the fixation of carbon into sugars in the stroma).

The differences between C3 and C4 plants may be introduced at this point, and tied to the earlier discussion about water loss through the stomata.

The reading assignment

The next lecture will cover cellular reproduction, the first topic in Unit Two of the textbook. Students will read Chapter 8 in Campbell, Mitchell and Reece, pp. 126-153.

Lecture 6 - Cell Division

Advance reading: Chapter 8, Campbell, Mitchell and Reece, pp. 126-153.

Objectives: In this lecture, students learn about the cellular processes of mitosis and meiosis. They learn that mitosis leads to exact genetic copies of cells and that meiosis is a sexual process that leads to variability in gametes. Students learn that cells go through a cycle, one part of which is cell division, and that cells growing in an uncontrolled or improper manner may become cancerous cells in a body.

CK Sequence links: Cell Division and Genetics [Gr.7§III, p. 176]

Cells have a way of making more cells.

The simplest case to consider is the fission of bacteria. This example illustrates the general principle that cells grow before they divide, and that they replicate their DNA so that a copy can be passed to each daughter cell. To a first approximation the two daughter cells appear identical, and a student can imagine continued and indefinite growth in a culture.

Protists often also reproduce by asexual cell division, but cell division becomes more complicated in the plant, animal and fungal kingdoms. Multicellular organisms typically have specialized somatic cells (e.g. neurons and muscle cells), and cell division may not lead to identical daughter cells during body development. In animals, a subset of the cells in the body are sequestered as germ cells (e.g. in our ovaries or testes). Dolly the sheep (and other cloned animals) notwithstanding, somatic animal cells generally have no future for reproduction beyond the lifespan of their body. The somatic cells of plants and fungi often have a broader growth potential than those of animals. For example, a branch of an orange tree can be grafted to the stump of a lemon tree, and the orange tree cells can develop blossoms and oranges (not lemons). The orange tree somatic cells retain the ability to divide and make pollen and egg cells. These general examples may help students understand the fundamental differences between somatic cells and germ cells, and between mitosis and meiosis. Cell division and organism reproduction may be synonymous in the prokaryotes and protists, but the two are typically distinct among the plants, animals and fungi.

The cell cycle consists of interphase (G1-S-G2) alternating with mitosis (prophase, metaphase, anaphase, telophase, cytokinesis) and these stages are important milestones for students to understand. Mitosis is also a rare opportunity to visualize a cellular process with a microscope. The class's attention should be directed to the movement and segregation of chromosomes, for it is this mechanical process that helps to explain why each daughter cell receives the same complement of DNA.

While presenting the concept of chromosome complements, the terms diploid and haploid should be introduced. The alternation between haploid and diploid stages in sexual reproduction can be easily explained using humans as an example (46 chromosome pairs). Meoisis should be distinguished from mitosis by its net result, the generation of haploid gametes. The alignment and segregation of chromosomes during the two meiotic divisions should be illustrated in such a way that students can appreciate the principle of independent assortment. It is important to mention that chromosomes undergo recombination during meiosis, so that the independent assortment of chromosomes can be distinguished from independent assortment of genetic loci (as in Mendel's laws) in the next lecture.

The reading assignment

The next lecture will cover some of the main ideas of classical genetics, a subject that was understood long before DNA was identified as the molecule carrying genetic information. Students will read Chapter 9 in Campbell, Mitchell and Reece, pp. 154-181.

Laboratory 3 – Mitosis and meiosis

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual,* 5th Edition. pp. 31-40

Objectives: In this laboratory, students learn how to list the events that occur as a plant or animal cell divides, stain tissues for identification of mitotic stages, and model the process of meiosis and gametogenesis.

CK Sequence Links: Cell structures and processes [Gr.5§II, p. 127], vascular plants [Gr.5§IIIA, p. 127], Cell division and genetics [Gr.7§III, p. 176]

All cells come from pre-existing cells, and most students would not need to be shown this before they would believe it! Nonetheless, the process of cellular division, and in particular the condensation and movement of chromosomes, is difficult to visualize from the "stick-figure" diagrams in textbooks. This laboratory allows students to see stained chromosomes in various states of condensation and segregation, and to visualize the fraction of cells in a population that are engaged in mitosis. This cannot substitute for careful study of diagrams, but is a useful supplement.

Outline- Slide and simulation work

I. Identification of mitotic stages in onion root tip

II. Identification of mitotic stages in whitefish blastula

III. Simulation of meiotic stages using chromosome models

IV. Identification of meiotic stages in Ascaris gametocytes

Lecture 7 - Genetics

Advance reading: Chapter 9, Campbell, Mitchell and Reece, pp. 154-181.

Objectives: In this lecture, students learn the principles of genetics established by Gregor Mendel; that there are alternate forms or alleles of genes which may be dominant or recessive in character, that higher plants and animals have two copies of each genetic locus, that the allele pairs segregate independently during gamete formation and are reconstituted during fertilization.

CK Sequence links: Cell Division and Genetics [Gr.7§III, p. 176]

Purebred vs. hybrid

One of the keys to understanding Mendel's work is appreciating his use of true-breeding characters in organisms. For example, he developed true-breeding stocks of purple-flowered pea plants and white-flowered pea plants, and these always remained purple or white respectively if they were genetically crossed with themselves. Students may appreciate that as a point of certainty, and can relate it to inbred pets as well. As they well know, a dog breeder who mates two beagle dogs does not reap a litter of dachshund puppies.

Mendel crossed true-breeding stocks with variation on the same character (such as flower color), and found an unusual result. In the case of crosses of true-breeding purple and white-flowered pea plants (called P generation for "Parental"), all of the progeny were purple-flowered. However, these purple-flowered pea plants (the F1 generation) differed from the purple-flowered parental (P generation) plants in that they were not themselves true-breeding. In self-pollination experiments, three quarters of the F2 generation plants had purple flowers and one quarter had white flowers. In this generation, all of the white-flowered plants were true-breeding, but only one third of the purple-flowered plants were true-breeding. The remaining two thirds of the purple flowered pea plants were identical to the purple-flowered F1 generation plants (i.e. their parents). The data are best represented in a 1:2:1 ratio of white-flowered to purple-flowered (non-true-breeding) to purple-flowered (true-breeding).

A striking result of this type of experiment is that genetic characters are irreducible. The pre-Mendelian thoughts on inheritance would have held that genetic characters are like paint; a genetic cross of purple and white flowered-plants would be akin to mixing purple and white paints. One would expect “violet-colored flowers” and “violet paint” respectively, and as one crossed the violet flowered plants with white-flowered plants the violet color would be gradually diluted further. What a surprise, then, to find that in the F2 generation there were true-breeding white flowered-pea plants that had no trace of purple color! It was as if the flower-color characteristic of the grandparent had been preserved without mixing, and then recovered.

With this experiment in mind, students can readily appreciate the idea that there are genes that determine characteristics such as flower color (i.e. a phenotype) and these genes are variable (i.e. there are different alleles of genes at the same genetic locus). The phenotype of an organism depends on which alleles are carried in its genotype, and whether the alleles are dominant or recessive with respect to each other. A Punnett square is a useful method for showing the proportions of genotypes expected in a genetic cross, and it draws upon the idea of genetic locus segregation during meiosis and random pairing of gametes during fertilization (discussed in the previous lecture). A second skill needed by students, besides an understanding of random assortment, is an ability to interpret genotypes represented in the Punnett square and predict the proportions of phenotypes.

Genetic crosses on two characters (e.g. wrinkled vs. smooth peas and purple vs. white flowers) can also be demonstrated by a more elaborate Punnett square, and tied to Mendel’s law of independent assortment.

The reading assignment

The next lecture will cover the principles of molecular biology, a logical extension of Mendelian genetics that helps to support students' understanding of inheritance. Students will read a portion of Chapter 10 in Campbell, Mitchell and Reece, pp. 182-207.

Lecture 8 - Molecular Biology

Advance reading: Chapter 10, Campbell, Mitchell and Reece, pp. 182-207.

Objectives: In this lecture, students learn about the replication of DNA (the basis for genetic inheritance), and the flow of genetic information from DNA to RNA to protein (the manifestation of inherited characteristics in a cell or organism).

CK Sequence links: Cell Division and Genetics [Gr.7§III, p. 176]

DNA is the genetic material

It was once thought that proteins might be the genetic material of cells, since they are seemingly more complex than nucleic acids and could carry more information. This belief was incorrect, in fact, and the Hershey-Chase experiment is a good example of the scientific method used to help prove that DNA is the genetic material.

The basic structures of nucleic acids (phosphate backbone, sugar, and base) should be presented along with Watson-Crick base pairing, so that students can understand the mechanics of DNA replication and transcription. A critical concept is that information is preserved during semiconservative replication, and RNA transcripts have the same coding content as the DNA (albeit with slightly different structural features). Students should learn that there are three principal types of RNA in a cell, rRNA, tRNA, and mRNA, and should know their basic functions during protein synthesis by ribosomes.

The universal genetic code is one of the major discoveries in science from the last 40 years, and students should understand the basic mechanics of how a ribosome decodes (translates) an mRNA transcript by reading triplets nucleotide sequences. With an understanding of codons, it is straightforward to discuss three types of mutations to DNA, and their effects in gene expression at the level of RNA and protein:

- Mis-sense mutations that change an encoded amino acid
- Silent mutations that do not change the amino acid coding of a gene

- Nonsense mutations that change the reading frame and usually result in truncation

The recent advances in genetic engineering are fascinating, and may be useful as examples that elicit student response and discussion. These may include transgenic plants and animals, agricultural and medical advances, and new diagnostic techniques that rely upon genetic engineering.

The reading assignment

With a solid foundation in Mendelian genetics and molecular biology, students can go on to study the genetics of populations. The background for this is found in chapter 13, Campbell, Mitchell and Reece, pp. 256-279

Laboratory 4 – Mendelian genetics

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual,* 5th Edition. pp. 187-198

Objectives: In this laboratory, students learn how to define and apply genetic terms, solve genetics problems by Punnett square, and analyze results of a cross in maize.

CK Sequence Links: Cell division and genetics [Gr.7§III, p. 176]

Hair and eye coloration are often treated in classroom studies as if they were a result of simple Mendelian inheritance, with blond hair and blue eyes usually regarded as the recessive states, but this is erroneous. These actually do not follow simple patterns of inheritance because they are not single-gene traits, and students are frequently misled on this point. There are a number of genetic diseases (sickle-cell anemia, hemophilia, cystic fibrosis) that follow simple patterns of inheritance, but it is poor form for a professor or teacher to enquire about the genetic diseases lurking in the family trees of students. In this laboratory, students will study a series of "safe" polymorphic human traits that do follow simple patterns of inheritance, but are not considered to be "abnormalities."

The teaching of genetics is an ethical challenge for professors, not only because genetic disorders in a student's family should not be callously discussed, but also due to the likelihood that some students might figure out that they are either adopted or that their "fathers" are not their biological fathers. A student may ask, for example, how he could possibly have type A blood when both of his parents are type O, and of course the most probable explanation (which is non-paternity) cannot be discussed. New mutations occur with some frequency, albeit a low one, and presenting that as a possible explanation for the abnormal pattern of inheritance is better than calling into question the mother's fidelity.

Outline- genetic analysis

I. Analysis of human traits
   A. PTC taster
   B. U-shaped tongue
   C. Widow's peak
   D. Free ear lobe
   E. Bent little finger
   F. Finger hair
   G. Hitchhiker's thumb

II. Solving genetics problems

III. ABO blood types

IV. Inheritance in maize (Indian Corn)
   A. Monohybrid cross
   B. Test cross or back cross
   C. Dihybrid cross

Lecture 9 - Genetics of Populations

Advance reading: Chapter 13, Campbell, Mitchell and Reece, pp. 256-279.

Objectives: In this lecture, students learn about adaptation and genetic variability in populations.

CK Sequence links: Evolution: (Evolution [Gr.7§V.A, p. 177] , Natural Selection [Gr.7§V.B, p. 177]); Biographies: Darwin [Gr.7§VI, p. 177]

Adaptation and populations

Students learn that adaptations are characteristics of an organism that help it to survive and reproduce in an environment. Gills, for example, are an obvious example of an adaptation to aquatic life, and lungs are an adaptation to terrestrial life. Unfortunately, discussions about adaptation often stray into examples that are less clear-cut, and it is important for scientists to resist the temptation to guess at a "purpose" for a trait, or even assume that there must always be one. The different species of finches on the Galápagos islands are a good example, as they include both seed-eating finches with large strong beaks, and insect-eating finches with smaller grasping beaks. The beaks may be adapted for specific diets, or perhaps the finch behavior that leads to either seed or insect-eating is adapted for the specific pre-existing beak. The concept of adaptation is extremely important, even if the order of events can be difficult to establish.

It is informative for students to read about Darwin's voyage on the HMS *Beagle*, and the logic underlying his theory of evolution by natural selection. Lamarck's proposal can be contrasted with Darwin's theory, and a discussion of the two can lead to the point that populations have pre-existing variation. A changed environment may be more favorable to some variants than others, and this is the basis upon which natural selection takes its toll. Darwin saw the process of evolution, which he referred to as "descent with modification", as a gradual accumulation of adaptations that might over time lead to a separation of populations into distinct species. The fossil record shows a historical sequence of organisms, and along with comparative anatomy and physiology of homologous structures it provides part of the evidence for evolution.

The conditions for Hardy-Weinberg equilibrium, an idealized state, are important to discuss because the various ways of violating the conditions provide underlying principles for microevolution. Mutation, natural selection, and non-random mating can easily lead to variation between two populations. The concept of a "founder effect" is also important, and an application of this is found in zoological parks that are attempting to save endangered species from extinction. The problem is that with only a few specimens extant, the genetic diversity of the breeding stock may be low. Many zoos trade individual animals to decrease the chances that they will create a genetic bottleneck and a weakened population.

The reading assignment

Chapter 14-15, Campbell, Mitchell and Reece, pp. 280-314.

Lecture 10 - The Origin of Species

Advance reading: Chapter 14-15, Campbell, Mitchell and Reece, pp. 280-314.

Objectives: In this lecture, students learn about the meaning of “species”

CK Sequence links: Classifying Living Things [Gr.5§I, p. 126], History of the Earth and Life Forms (Paleontology and Geologic Time) [Gr.7§IV, p. 177], Evolution: (Evolution [Gr.7§V.A, p. 177], Natural Selection [Gr.7§V.B, p. 177], Extinction [Gr.7§V.C])

Species and speciation

Organisms are classified by a hierarchical system that starts with kingdoms (e.g. plant or animal) and ends with species (e.g. chimpanzee or human). Individual organisms are said to be in the same species if they can interbreed and produce fertile offspring. A similarity of appearance may not provide assurance that two animals are in the same species, as the example of the western and eastern spotted skunks indicates. Conversely, two animals may have widely different features (such as artificially-selected breeds of dogs) and yet still be in the same species. The definition of species is complicated by the fact that organisms may be said to be in different species (e.g. dogs, coyotes and wolves) and yet still yield fertile hybrid offspring. Two organisms (such as protozoans) can also be considered to be in the same species even though their asexual life cycles prevent any test for interbreeding.

The meaning of "species" is not strict, and it is worth discussing some of the possible exceptions. The following question might be posed regarding the example of the eastern and western spotted skunks: Suppose that it were shown by a molecular biologist that the differences in reproductive behavior were due to an allelic difference at a single genetic locus. Would it still be reasonable to distinguish the eastern and western variants as different species if they only differed by a slight genetic change? There is no definitive answer to such a question, but most biologists would not accept a single genetic polymorphism as being worthy of the title "species." Nonetheless, the type of reproductive (temporal) isolation discussed for the eastern and western spotted skunks could be the basis of more significant speciation, a process that might lead to many additional differences accumulating over tens or hundreds of thousands of years. Other types of reproductive barriers include the prevention of mating or fertilization (habitat, behavioral, mechanical, or gametic isolation), or a lack of development of viable, fertile offspring after mating.

There are two important models for the pace of evolution, one of which holds that lineages develop slowly and the other that species develop in "spurts" that occur infrequently. The fossil record is not simple to interpret, and it is possible that both models are true to some extent. Catastrophic changes in the environment may have occurred at times during earth's history, leading to extinctions and dramatic shifts in the remaining life forms.

While scientists cannot literally go back in time to study these events, the study of evolution is not a static field. Bees and termites preserved in amber have been a source of DNA from the Tertiary period (25-40 million years ago), and DNA has been sequenced from an amber-entombed weevil dating to 120 million years ago (Nature 363: 536-8. 1993). There is also some preservation of ecological data: DNA extracted from the 20,000-year old dung of an extinct ground sloth has been used to identify the types of plants in its diet (Science 281: 402-6. 1998). In several cases, dormant bacteria have been revived from ancient samples (e.g. from the gut of a 25 million-year old extinct bee, or from a 250 million-year-old Permian salt crystal) and these living fossils can be compared to modern species (Science 268, 1060-1064. 1995; Nature 407, 897 - 900. 2000).

The reading assignment

Chapter 16, Campbell, Mitchell and Reece, pp. 316-343

Laboratory 5 – Population Genetics and Evolution

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual*, 5th Edition. pp. 211-216

Objectives: In this laboratory, students learn the basis of Hardy-Weinberg equilibrium, and the effects of natural selection on stable gene frequencies. They learn about the principles of adaptation and competition.

CK Sequence Links: History of the Earth and Life Forms (Paleontology and Geologic Time) [Gr.7§IV, pp. 177-8], Evolution: (Evolution [Gr.7§V.A, p. 178], Natural Selection [Gr.7§V.B, p. 178], Extinction [Gr.7§V.C, p. 178])

The Hardy-Weinberg Law is probably obeyed as frequently as a new red light on a New York City street, both being theoretical constructs seemingly made to be ignored. The reason that the Hardy-Weinberg equilibrium is important to discuss is that its five preconditions illustrate how the non-idealized world really works. We do find micro- and macro-evolution on earth, and that is precisely for the reason that the genetic alleles in a population are not typically at equilibrium.

Outline- simulation work

I. Simulation of Hardy-Weinberg equilibrium

II. Simulation of natural selection

III. Adaptations in plants and animals

   A. Adaptations to desert-like habitats

   B. Adaptations to get the sunlight

   C. Adaptations to aquatic habitats

   D. Adaptations for living in nitrogen-deficient soil

   E. Mimicry and camouflage

   F. Divergent evolution

   G. Convergent evolution

H. Dispersal

Lecture 11 - Microbial Evolution

Advance reading: Chapter 16, Campbell, Mitchell and Reece, pp. 316-343.

Objectives: In this lecture, students learn about the diverse types of microbial life on earth, and their evolution.

CK Sequence links: The Human Body (Germs, Diseases, and Preventing Illness) [Gr.1§II.B, p. 38], Science Biographies: Pasteur [Gr.1§VIII, p. 39], Classifying Living Things (Protists) [Gr.5. §I, p. 126], Evolution [Gr.7§V, p. 177].

Prokaryotes and protists - life of a single cell

The fossil evidence indicates that the first cells on earth appeared within several hundred million years of its formation. These were similar to prokaryotic organisms that are seen today, in that they appeared to have a simple organization and lack a nucleus. These microorganisms were photosynthetic, and generated the first oxygen for the earth's atmosphere. The origin of these first cells is a matter of debate, but they may have been based on self-replicating RNA molecules as both a biochemical catalyst and genetic material.

There are two major branches of prokaryotes, called eubacteria and archea (archaebacteria). The genes of archaea differ significantly from those of eubacteria, and they lack a peptidoglycan cell wall. Archea resemble eukaryotes in many respects, and it is believed by many scientists that the first eukaryotic cell was derived from an archean ancestor.

Prokaryotes have a limited number of cell shapes (cocci, bacilli, and spirochetes), compared to eukaryotes that have a cytoskeleton and can adopt a wider variety of shapes (e.g. a nerve cell vs. a blood cell). Prokaryotes can be autotrophic, using carbon dioxide as a carbon source, or heterotrophic, using organic molecules made by others. The source of energy can be either chemical or sunlight. The archaea are often called "extremophiles" because they grow under environmentally harsh conditions, such as hot springs, brine pools, or anaerobic sediments.

Many eubacteria cause diseases in humans, and these include infections (such as Streptococcus in "Strep throat") and toxin-producing bacteria that cause food poisoning (such as pathogenic strains of Escherichia coli or Salmonella in beef and chicken, respectively). Other bacteria are normal "flora" in our gut, and are beneficial (for example as a source of vitamin K).

Protists are single-celled eukaryotic organisms, and are extremely complex in comparison to prokaryotes. The major types include archaezoa (such as the parasites *Trichomonas* and *Giardia* that do not have mitochondria), euglenozoa (such as *Euglena*, having a flagellum for mobility), alveolata (including the marine dinoflagellates that cause red tide, *Plasmodium* that causes malaria, ciliated organisms such as *Paramecium*, and amoebae and slime molds such as *Physarum*), and stramenopila (including diatoms, golden and brown algae, and water molds). Protists can be autotrophic (such as photosynthetic dinoflagellates or algae), or heterotrophic (such as the blood parasite *Trypanosoma brucei* that causes African sleeping sickness). Heterotrophic protists are often called "protozoa", and are likely to have been the ancestors of fungi and animals.

It is informative to study patterns of colonization in protists (e.g. *Volvox*, or other algae), as these are simple cases in which cells have specialized roles and are interdependent. There has been a shift in classification so that many organisms formerly considered plants and fungi are now classified as protists. This may also happen in the animal kingdom, as the type of colonization seen in some protists is not dissimilar from that seen in sponges (Porifera).

The reading assignment

Chapter 18, Campbell, Mitchell and Reece, pp. 344-365.

Lecture 12 - Plant Diversity

Advance reading: Chapter 17, Campbell, Mitchell and Reece, pp. 344-365.

Objectives: In this lecture, students learn about the diverse types of plants on earth, from mosses and ferns through pine trees, corn, and bean plants.

CK Sequence links: Plant and plant growth [Gr.K§I, 19], Life Cycles [Gr.2§I.B, p. 59], Classification of Living Things [Gr.5. §I, p. 126], Plants: vascular and nonvascular [Gr.5§III.A, p. 127], reproduction [Gr.5§III.C, 137], Life cycles and reproduction [Gr.5§IV.A, p. 128], Evolution [Gr.7§V, p. 177]

Plant life on earth

Students learned about algae in the previous lecture, and it may be valuable to compare the overall structure of a simple colonial protist such as *Ulva* with a vascular terrestrial plant. One of the challenges faced by terrestrial plants is maintaining adequate gas exchange in the leaves while not losing an excessive amount of water vapor. The need to communicate minerals from soil to leaves, and fixed carbon from leaves to other parts of the plant, are also important.

Bryophytes (e.g. mosses) have a cuticle to prevent loss of moisture, but lack vascular tissues and the rigid support they provide. Ferns have a xylem and phloem for vascular transport, roots, and rigid stems that can support heavy fronds. Both ferns and mosses have flagellated sperm for fertilization. Seed-bearing plants are vascular, and include the gymnosperms (e.g. confers such as pine) and angiosperms (e.g. flowering plants). During their life cycle, these use pollination to transfer non-flagellated sperm-forming cells to a recipient plant for fertilization. All plants have a sexual life cycle, however it is important to distinguish the haploid (gametophyte) and diploid (sporophyte) phases and their importance in mosses, ferns, and seed-bearing plants. The parts of a flower are important information, as are the principles of pollination by wind, insects, or birds, and physical and biological mechanisms of seed dispersal.

Fungi were once classified as plants, although they are not photosynthetic and actually bear many similarities to animals. Fungi secrete digestive enzymes that break down food outside of the cell, and small molecular products are imported into the cell. Students may be surprised to learn that this is exactly how animal cells obtain their energy (topologically, humans are the same as doughnuts - the lumen of an intestine is "outside" the body, and so like fungi we also use external digestion). Protozoans, which were discussed in the previous lecture, engulf bacteria or other cells rather than breaking them down externally. Fungi have three phases in their life cycle: A haploid spore and mycelial stage, a dikaryotic phase and fruiting body in which a mycelium contains two different types of nuclei, and a diploid phase that precedes meiosis. Lichens are an interesting example of mutualism between two organisms; a fungus and alga.

The reading assignment

Chapter 18, Campbell, Mitchell and Reece, pp. 366-397.

Laboratory 6 – Kingdom Plantae – Division Anthophyta (Angiosperms)

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual*, 5th Edition. pp. 109-117

Objectives: In this laboratory, students learn to identify the parts of flowering plants, and describe their life cycles.

CK Sequence Links: Plant and plant growth [Gr.K§I, p. 19], Life Cycles [Gr.2§I.B, p. 59], Plants: vascular and nonvascular [Gr.5§III.A, p. 127], reproduction [Gr.5§III.C, p. 127], Life cycles and reproduction [Gr.5§IV.A, p. 128]

This is an essential laboratory for future elementary school teachers, because it provides them with a wealth of information on flowering plants. Learning the parts of a flower is an exercise in memorization, but that should not be seen as a bad thing! Students will learn by this exercise that there is tremendous morphological variation between floral species, but certain structures are consistently present. Instead of having to learn a new set of names for the flower parts of each every species, students are being shown a pattern that simplifies nature. This type of positive attitude is important to imbue in future teachers.

Outline - learning the parts of plants

I. Floral anatomy
   A. Labeling of illustration
   B. Dissection
II. Fruit
III. Seed
   A. Bean
   B. Bean seedling
IV. Carpel theory

V. Monocots and dicots

Lecture 13 - Animal Diversity

Advance reading: Chapter 18, Campbell, Mitchell and Reece, pp. 366-397.

Objectives: In this lecture, students learn about characteristics of nine phyla of animals. While studying animal biology, it is also a good point to discuss adaptation to environment and evolution.

CK Sequence links: Life Cycles [Gr.2§I.B, p. 59], Insects [Gr.2§II, p. 59-60], Classification of Animals [Gr.3§I, p. 81], Classification of animals [Gr.5.§I, p. 127]

Survey of animals, from sponges to humans

The following phyla should be surveyed: Porifera, Cnidaria, Platyhelminthes, Nematoda, Mollusca, Annelida, Arthropoda, Echinodermata, and Chordata. Within a discussion of these phyla, there are several features that should be compared and receive attention:

- Cell specialization (e.g. choanocyte and amoebocyte in sponges)
- Symmetry (e.g. radially symmetrical hydra vs. bilaterally symmetrical flatworm)
- Digestive system (e.g. absorption of nutrients by tapeworms, a single mouth in corals and planarians, mouth and anus in nematodes)
- Body cavity (e.g. no cavity in a flatworm, pseudocoelom in a roundworm, and coelom in a segmented worm)
- Segmentation (e.g. in earthworms, insects, and humans)
- Body skeleton (e.g. exoskeleton in arthropods, endoskeleton in echinoderms and chordates, hydrostatic skeleton of annelids)
- Growth patterns and life cycle (e.g. polyp and medusa stages in some cndarians, molting in arthropods, metamorphosis in insects and amphibians)
- Support and locomotion (e.g. muscle tissue to change body shape in hydras and helminths, the "foot" of mollusks, use of water pressure by jellies and cephalopods, flight in insects, and role of exo or endoskeletal system in anchoring muscles)

It is important that students develop a solid grasp of the facts that underlie how animals live in their environment; how they eat, move, grow, and reproduce. A more detailed look at the chordates, and in particular the vertebrates, is warranted. Vertebrates have a skull and backbone, and most have hinged jaws. Fish are classified as being cartilaginous (e.g. sharks and rays) or bony fish (e.g. goldfish). Amphibians have adaptations that permit both aquatic and terrestrial aspects to their life cycles, and reptiles are still less-dependent on water. Birds evolved from reptile-like ancestors, as did mammals. The egg-laying monotremes, marsupial and placental mammals should be distinguished, particularly with regard to their characteristics of development.

The reading assignment

Chapters 20-21, Campbell, Mitchell and Reece, pp. 412-449.

Lecture 14 - Animal Form and Function, and Nutrition

Advance reading: Chapters 20-21, Campbell, Mitchell and Reece, pp. 412-449.

Objectives: In this lecture, students learn some of the fundamental aspects of animal physiology, and focus on the digestive system specifically.

CK Sequence links: Animals and their needs [Gr.K§II, p. 19], The Human Body [Gr.K§III, p. 19], Special Classification of Animals [Gr.1§I.D, p. 37], Body Systems [Gr.1§II.A, p. 38], Human Body: (Cells [Gr.2§III.A, p. 60], Digestive/excretory [Gr.2§III.B, p. 60], Healthy Diet [Gr.2§III.C, p. 60]), Evolution [Gr.7.§V, p. 177]

Structure and function in the animal

Students learn about the general principle in biological science that there is a relationship between structure and function. For example, a bird has flight muscles, hollow bones, and feathers, and the seemingly minor details of structure are important in the function of flight. Each of these structures may be said to be an adaptation, continuing a discussion from a previous lecture, however complexity in structure may cause confusion about evolution. A student may ask "How could such an intricate set of specialized structures evolve for flight, when a lack of any one adaptation might render the entire wing nonfunctional?" The answer is that wings probably did not evolve to their present form in birds in a single step, and each structure that now seems to be specialized for flight may have actually evolved for a different function. Feathers may have evolved initially as lightweight insulation, protecting an animal from cold wind and water. Gliding from treetop to ground may have evolved as a function that preceded flying, and would not have required strong flight muscles or lightweight bones. The function of gliding short distances may have evolved into soaring behavior, which may have gradually evolved into powered flight, with each improvement in function accompanied by an increase in structural complexity. Structure and function go hand in hand, however the students should be cautioned that function and structure may have only "met" in recent evolutionary history.

The human body is made up of just a few types of tissues, including epithelial sheets, connective tissue, muscles and nerves. Some assemblages of tissues are called organs, and some groupings of organs and tissues are called organ systems. These systems are all integrated in the body to maintain homeostasis. Teaching human physiology is a delicate balancing act. The body should be presented in a way that is reductionist (so that the complex organism can be understood as a collection of functions and accompanying organ systems), but not overly reductionist (it is not helpful to view the body as being a collection of cells or molecules).

The digestive system is a good place to begin the discussion of human physiology because it builds upon the prior discussion of fungal and animal kingdoms (a characteristic of these heterotrophs being external digestion), and the increase in sophistication of the gut in animal phyla ranging from Porifera to Chordata. In humans, mechanical and enzymatic digestion is associated with each "step" in the alimentary canal (e.g. mouth, stomach, and intestine). In the lumen of the gut, the food is broken down to the level of molecules that can be absorbed by cells. Nondigestible materials are excreted in the feces. Urine, which will be discussed in a later lecture, is based on wastes that are removed from the blood (i.e. not food wastes). It is important to discuss the role of the large intestine in recovery of water, in no small measure because diarhea-causing illnesses are the leading cause of death among children world-wide. It is also important to discuss the elements of a healthy diet, which includes a balance of carbohydrates, proteins, fats, vitamins, and salts and minerals.

The reading assignment

Chapters 22-23, Campbell, Mitchell and Reece, pp. 450-481

Laboratory 7 – Kingdom Animalia – Phylum Chordata – *Rana pipiens*

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual,* 5th Edition. pp. 177-183

Objectives: In this laboratory, students learn to identify the parts of a leopard frog by dissection.

CK Sequence Links: The Human Body [Gr.K§III, p. 19], Special Classification of Animals [Gr.1§I.D, p. 37], Body Systems [Gr.1§II.A, p. 38], Human Body: (Cells [Gr.2§III.A, p. 60], Digestive/excretory [Gr.2§III.B, p. 60], Healthy Diet [Gr.2§III.C, p. 61]) , Human Body: (Muscular System [Gr.3§II.A, p. 81], Skeletal System [Gr.3§II.B, p. 81], Nervous System [Gr.3§II.C, p. 82]), Human Body: (Circulatory System [Gr.4§I.A, p. 104], Respiratory System [Gr.4§1.B, p. 104]), Life Cycle and Reproduction [Gr.5§IV.A, p. 128], Sexual Reproduction in Animals [Gr.5§IV.B, p. 128], Human Body: (Endocrine System [Gr.5§V.B, p. 128], Reproductive System [Gr.5§V.B, p. 128]).

The number of linkages between this laboratory and the Core Knowledge Sequence is an indication of its importance for aspiring teachers. Students will study the external and internal anatomy of the frog so that they may see in practice the organ systems that they are learning about in the lecture. A series of dissection exercises is provided in the laboratory manual so that students can work slowly and deliberately, and learn the most from each specimen.

Outline - foundation of vertebrate anatomy

I. External anatomy

II. Internal anatomy

A. Digestive system

B. Respiratory system

C. Urogenital system

D. Circulatory system

E. Nervous system

Lecture 15 - Respiratory and Circulatory Systems

Advance reading: Chapters 22-23, Campbell, Mitchell and Reece, pp. 450-481.

Objectives: In this lecture, students learn how oxygen and nutrients are efficiently distributed to all of the cells in the human body, and cellular wastes and carbon dioxide removed.

CK Sequence links: Human Body: (Circulatory System [Gr.4§I.A, p. 104], Respiratory System [Gr.4§1.B, p. 104]).

Heart and lungs

In a previous lecture, students learned that cells in the human body need oxygen to conduct oxidative phosphorylation in the mitochondria and generate carbon dioxide. In a protist organism, the oxygen and carbon dioxide can readily enter and exit the cell by diffusion, but in a multicellular organism such as a human the rate of diffusion would be too low to service the cells in the interior of the body by such a method. This problem is overcome by having a system of blood vessels that extend to all living tissues, supplying the cells with fresh oxygen and nutrients and removing wastes. Every living cell in the human body is within close proximity of a capillary bed, and so diffusion is still the mechanism by which the exchange takes place. Respiration and circulation are the means by which this oxygen distribution and waste recovery system is maintained.

A critical concept for the discussion of diffusion is surface area. Just as the intestinal walls are made up of villi to increase surface area and adsorptive capacity, the lungs have a substantial internal surface area made up of alveoli. Oxygen from the air becomes dissolved on the moist surface of the alveoli, and diffuses into the blood where it is bound by hemoglobin in the red blood cells. At the capillary beds in the tissues, the hemoglobin releases its oxygen (in response to a low pH "cue") and the oxygen diffuses into the surrounding cells. Carbon dioxide generated by metabolically active cells is dissolved in the blood and binds to the hemoglobin in red blood cells, by which means it is transported back to the lungs and released.

The overall flow of blood, alternating between pulmonary and systemic circulation, should be understood by students, and the differing structures of arteries and veins discussed. The diseases emphysema, atherosclerosis, and other cardiopulmonary disorders are helpful in educating students about human health, and for explaining the functions of the body systems that they affect.

The reading assignment

Chapters 24-25, Campbell, Mitchell and Reece, pp. 482-515

Lecture 16 - Immune System and Homeostasis

Advance reading: Chapters 24-25, Campbell, Mitchell and Reece, pp. 482-515.

Objectives: In this lecture, students learn about how the body defends itself against infections, and how it maintains a stable internal environment.

CK Sequence links: Germs, Diseases and Illness [Gr.1§II.B, p. 38], Digestive/excretory [Gr.2§III.B, p. 60], Human Body: Lymphatic/immune System [Gr.6§V, p. 154].

Infection and immunity

Through several previous lectures, there has already been a foundation laid for discussing pathogenic bacteria and viruses, and parasitic protozoans. This current lecture includes a discussion of several of the mechanisms by which the immune system recognizes the body as "self" and the invading organism as "non-self," and how it attacks and destroys foreign materials. A good example for students to consider is the type of response the body mounts to a skin wound. Phagocytic cells are attracted to the site of a wound by chemical signals, and engulf debris and bacteria that may be present.

Invading organsims may also be attacked by antibodies (from B-lymphocytes) and cytotoxic T-lymphocytes, but the body takes several weeks to mount an attack against a new "antigen." Once the body has been exposed to a foreign antigen however, memory B-lymphocytes maintain the immune surveillance for years. That is the basis for how vaccinations protect an individual from a specific infectious disease, sometimes for life.

The internal environment

Just as a modern skyscraper must have systems for sewage disposal, and regulation of temperature, humidity, and air exchange, the human body must dispose of nitrogenous wastes in urine and maintain an internal core temperature, water and salt balance. Proteins and nucleic acids contain nitrogen atoms, and their metabolic wastes would be toxic to humans if stored and excreted in the form of ammonia. Mammalian cells excrete nitrogen wastes in the form of urea, which is water soluble and less toxic than ammonia. The bloodstream collects these cellular wastes and the kidneys remove them from the blood by filtration, reabsorption, and secretion. The urine excreted by the kidneys is a small fraction of the original filtrate, and is collected in the urinary bladder.

The difference between endothermic and exothermic animals is an important point for students to understand. In endotherms, the metabolic processes are the primary source of body heat, while in ectotherms the environment is the primary source of body heat. A lizard may "sun itself" to raise its body temperature while a human may shiver to increase the metabolic rate in muscles.

The reading assignment

Chapters 26-27, Campbell, Mitchell and Reece, pp. 516-561

Laboratory 8 - Blood and Circulation

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual*, 5th Edition. pp. 239-246

Objectives: In this laboratory, students learn about the cellular components of blood, and how to measure heart rate and blood pressure. Students learn to listen for heart sounds (AV and semilunar valves) and locate valves in veins.

CK Sequence Links: Human Body: (Circulatory System [Gr.4§I.A, p. 104], Human Body: Lymphatic/immune System [Gr.6§V, p. 154].

Students learn about the types of cells found in blood, building upon what they have already learned about the immune cells (such as lymphocytes) and oxygen and carbon dioxide-carrying erythrocytes. Studying circulatory physiology is an important part of this lab, and many of the exercises may be adapted for elementary school students.

The movement of erythrocytes may be observed directly in the thin skin of a frog's foot web, using a microscope. This, or an analogous inspection of a goldfish tailfin, is a useful way of allowing students to measure cell movement in capillary beds. Coupled with a discussion of flow rates through larger veins and arteries, students can develop a sense of the extent of capillary networks in the tissues.

Outline - study of the blood and its circulation

I. Blood characteristics - analysis of blood smears
   - A. Erythrocytes (red blood cells)
   - B. Leukocytes (lymphocytes)
   - C. Blood platelets

II. Physiological Properties of Blood
   - A. Blood type
   - B. Clotting time

C. Hemoglobin levels

D. Hematocrit

III. Circulatory physiology

A. Heart sounds

B. Heart rate

C. Pulse rate

D. Blood pressure

E. Valves in veins

IV. Circulatory pattern in frog's foot (or goldfish tail)

Lecture 17 - Endocrine and Reproductive Systems

Advance reading: Chapters 26-27, Campbell, Mitchell and Reece, pp. 516-561.

Objectives: In this lecture, students learn about the hormonal signals used for communication between organs, and the processes of sexual reproduction and embryonic development.

CK Sequence links: Life Cycle and Reproduction [Gr.5§IV.A, p. 128], Sexual Reproduction in Animals [Gr.5§IV.B, p. 128], Human Body: (Endocrine System [Gr.5§V.B, p. 128], Reproductive System [Gr.5§V.B, p. 128]).

Chemical regulation

A number of independent sites in the body secrete hormones, and these include the hypothalamus, the pituitary, the thyroid, the adrenal, the testes or ovaries, and the pancreas. The release of hormones may be in response to a neurological signal from the brain (e.g. adrenaline release) or another hormone (e.g. glucocorticoids released in response to adrenocorticotropic hormone, itself released in response to a "releasing hormone" from the hypothalamus). Students should learn about homeostasis and "feedback-loops" in the endocrine system, with the insulin/glucagon hormone pair being a particularly good example for discussion in the context of the disease diabetes mellitus. In addition, the effects of thyroid hormone deficiency (e.g. goiter, from iodine deficiency) and growth hormone deficiency (dwarfism) should be presented.

Reproduction and embryogenesis

A discussion of the human reproductive system fits will with the discussion of the endocrine system, because of the importance of hormones in sperm and egg production and in birthing from the uterus. The female menstrual cycle is under the control of the hypothalamus and pituitary, for example, and a discussion of the rise and fall of estrogen levels prior to ovulation is important. The triggering effects of lutenizing hormone and follicle stimulating hormone, and the support of the endometrium by progesterone are also important. Students will already appreciate the genetic implications of sexual and asexual lifecycles from previous lectures, but students' prior knowledge of the anatomy of sex organs and human sexual response are easily overestimated. The mechanism of ovulation and the role of the fallopian tubes in transport of the egg cell should be discussed, as should generation, storage, and ejaculation of sperm cells in semen.

The fundamentals of early embryogenesis should be presented, starting with generation of the blastula (blastocyst) and invagination to produce a gastrula. The pattern formation that shapes the embryo is based on chemical signals, and it is worthwhile discussing the types of grafting experiments that demonstrate tissue induction. The role of the placenta and umbilical cord should be discussed in the context of human development.

The reading assignment

Chapters 28-29, Campbell, Mitchell and Reece, pp. 562-599

Lecture 18 - Nervous System and the Senses

Advance reading: Chapters 28-29, Campbell, Mitchell and Reece, pp. 562-599.

Objectives: In this lecture, students learn how stimulus and response are connected in the body, and how their brains can think about such things.

CK Sequence links: The Human Body [Gr.K§III, p. 19], Human Body: (Nervous System [Gr.3§II.C, p. 82], Vision [Gr.3§II.D, p. 82], Hearing [Gr.3§II.E, p. 82]).

Stimulus, response, and thought

Students should learn that neurons are the fundamental units that make up the nervous system, and that signals are propagated by electrical and chemical means. The action potential is also an important concept, because it permits amplification of an electrical signal that has reached a threshold. Students should understand how an action potential can regenerate and spread down a cell body, and how myelination increases the rate of propagation. Knowledge of the parts of a neuron (dendrites, cell body, axon, nodes of Ranvier, and synaptic knobs) is important, and students should know how neurons meet at a synaptic cleft and propagate a signal by secretion of a neurotransmitter.

The peripheral nervous system is separated into sensory and motor divisions, and students should know which major body functions are autonomic (e.g. pupil constriction and dilation) and which are not (e.g. skeletal muscles). The roles of sensory neurons, interneurons, and motor neurons should be discussed, along with the major divisions of the central nervous system(e.g. spinal cord, cerebellum, cerebrum). The integration of different portions of the central nervous system in coordination, decision-making, and memory, are all important concepts.

The five senses provide information to the nervous system, and in all cases the sensory cells form a synapse with a sensory neuron that generates an electrical signal. Touch is based on sensory receptor cells that detect mechanical changes, pain, and temperature changes. Stretch receptors also provide our body with proprioception, the ability to detect and monitor the positions of our limbs and other body parts. Hearing is based on "hair cells" in the cochlea that detect pressure changes, and taste and smell are based on chemical receptor cells. Eyesight is based on photoreceptor cells (rods and cones) that form synapses with neurons leading to the optic nerve. The anatomy of the eye and ear are excellent examples for students to study, because the physical (optical and mechanical) characteristics of the structures are well understood.

The reading assignment

Chapter 30, Campbell, Mitchell and Reece, pp. 600-616

Laboratory 9 - Sensory Mechanisms

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual*, 5th Edition. pp. 257-267

Objectives: In this laboratory, students learn the details of the structures underlying the senses of touch, taste, smell, sight, and hearing.

CK Sequence Links: Human Body: (Vision [Gr.3§II.D, p. 82], Hearing [Gr.3§II.E], p. 82.

In these exercises students learn the basic structures of sensory tissues, including skin receptors, taste buds, auditory and visual organs. Some of the exercises are directly related to measuring sensation (such as bone conduction of sound waves), while others are related to secondary perceptions (such as demonstration of visual afterimages). Many of the laboratory activities (such as the two-point discrimination test) can be easily adapted to an elementary classroom.

Outline - study of the structure and function of sensory organs

I. Cutaneous structures

- A. Skin structures
- B. Skin sensation

II. Taste and smell

- A. Microscopic examination of slides
- B. Distinguishing between taste and smell

III. Auditory and equilibrium senses

- A. Ear structures
- B. Experiments on the ear

IV. Visual sense

- A. Eye structure - dissection
- B. Functioning of eye

Lecture 19 - Movement

Advance reading: Chapter 30, Campbell, Mitchell and Reece, pp. 600-616.

Objectives: In this lecture, students learn how muscles and a skeleton work together.

CK Sequence links: Insects [Gr.2§II, p. 59], Human Body: (Muscular System [Gr.3§II.A, p. 81], Skeletal System [Gr.3§II.B, p. 81]).

Muscle and bone

The human skeleton is important for support and protection, but also for anchoring muscles used in movement. Students should know the names of the major bones in the human skeleton (e.g. humerus, radius, and ulna in the arm) and the types of joints between them. Muscles are anchored to bone through tendons, and constriction causes the application of force. The triceps and biceps muscles of the arm are useful examples of the type of leverage that can be applied through the skeleton.

The cellular and molecular bases of muscle contraction are well understood, and this is an opportunity to link the energy requirements of muscle contraction with discussions of ATP generation in previous lectures. Muscles are composed of bundles of fibers (cells), which are themselves composed of smaller myofibrils. The relative movement of actin and myosin filaments is controlled by ATP hydrolysis and calcium ion binding. Motor neurons, which were discussed in a previous lecture, form synapses with muscle fibers that are called neuromuscular junctions. The action potential from a motor neuron causes the mobilization of calcium ions from the endoplasmic reticulum into the cytoplasm of the muscle cell, and this causes sliding of the actin and myosin filaments (at the molecular level) and contraction of the sarcomere. The muscle relaxes when the action potentials in the motor neuron cease.

The reading assignment

Chapter 31, Campbell, Mitchell and Reece, pp. 618-639

Lecture 20 - Plant Form and Function

Advance reading: Chapter 31, Campbell, Mitchell and Reece, pp. 618-639.

Objectives: In this lecture, students learn about the major divisions of flowering plants, and some of the details of their structure.

CK Sequence links: Plant and Plant Growth [Gr.K§I, p. 19], Plants: (Non-vascular and Vascular [Gr.5§III.A, p. 127], Reproduction [Gr.5§III.C, p. 127]).

Vascular plant structure and function

This lecture extends a previous discussion of plants that was initiated on the topic of evolutionary "diversity" in the plant kingdom. The flowering plants are classified as monocots or dicots, based on the number of embryonic leaves called cotyledons. Monocots, which include grasses, corn, and iris flowers as examples, tend to have parallel leaf veins and a broad and fibrous root. Dicots, which include deciduous trees, bean plants, and clover, have branched leaf veins and a principal taproot. Students should know the anatomy of plants (roots, stems, leaves) and the functions of each of the parts. The growth patterns of plants that use runners or develop tubers should also be discussed, along with the terms "annual," "perennial," and "woody" plants.

Plant growth occurs at tissues called meristems, and plant cells form three principal types of tissues: epidermis, vascular tissue, and ground tissue. In monocots and dicots, the vascular and ground tissues are organized differently, but all vascular tissues are made up of xylem (water conducting) and phloem (sugar-conducting) cells.

The development of the male gametophyte (pollen) and female gametophyte (embryo sac) are important concepts, and students can compare these haploid structures with their counterpart gametophytes in mosses and ferns (as previously discussed). The process of pollination, pollen tube growth into the ovary, and sperm transfer should be discussed, and students should know that the fertilized ovule develops into a seed while the ovary develops into a fruit. Asexual (or vegetative) reproduction is important in the growth of many plants, and is a testimonial to the pluripotency of plant cells. Many important agricultural crops are propagated by vegetative reproduction, which leads to genetically identical plants.

The reading assignment

Chapters 32-33, Campbell, Mitchell and Reece, pp. 640-676

Laboratory 10 - Vegetative structures of angiosperms

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual*, 5th Edition. pp. 119-128

Objectives: In this laboratory, students learn the structures and functions of roots, stems, and leaves.

CK Sequence Links: Plant and Plant Growth [Gr.K§I, p. 19], Plants: (Non-vascular and Vascular [Gr.5§III.A, p. 127]).

Plants are easy to incorporate into elementary and middle school science teaching, but in doing so it is essential that the teacher be in possession of a wealth of facts and knowledge about plants. The root, for example, has a growing tissue called the "root meristem" that is protected by a "root cap." Minute structures called "root hairs" increase the absorbancy of the root. The stems and leaves similarly have detailed features that are important in their function. A substantial part of this laboratory activity is the study of cross-sections of plant parts, to visualize the vascular structures and their variation between different species.

Outline - The parts of plants

I. Root
   - A. Root structures
   - B. Root classification

II. Stem
   - A. External features
   - B. Cross-section: Dicot and monocot structures

III. Leaf
   - A. External features
   - B. Leaf cross-section: structures

Lecture 21 - Plant Nutrition and Physiology

Advance reading: Chapters 32-33, Campbell, Mitchell and Reece, pp. 640-676.

Objectives: In this lecture, students learn some of the fundamentals of plant physiology, including transport of minerals and nutrients, control of growth, and environmental response.

CK Sequence links: Plant and Plant Growth [Gr.K§I, p 19], Science Biographies: Carver [Gr.K§7, p. 20], Seasonal Cycles [Gr.2§I.A, p. 59], Plants: Non-vascular and Vascular [Gr.5§III.A, p. 127].

Plant growth and environmental response

Students will recall from earlier discussions of photosynthesis, that plants acquire carbon dioxide from the air and "fix" it into organic molecules. Nitrogen is acquired from the roots (often with the assistance of nitrogen fixing bacteria), and other minerals such as phosphorus and magnesium are also taken up by the roots. The flow of inorganic materials in the xylem sap is caused by transpiration in the leaves, while movement of sugar throughout the plant is based on active transport and conducted by the phloem sap. Students should learn about some of the issues related to agriculture and crop yield, including sources of nitrogen in planted fields.

The phototropic response of plants has a hormonal basis (auxins), and students should study the early experiments that demonstrated the effect of the shoot tips on phototropic behavior of grasses, and the role of auxins in cell elongation. Gravitropism and thigmotropism are also environmental responses that lead to changes in growth pattern. The discussion of plant hormones should be included to include the effects of cytokinins in stimulating cell division, giberellins in affecting fruit development, and ethylene gas in controlling fruit ripening.

The reading assignment

Chapter 34, Campbell, Mitchell and Reece, pp. 678-697

Lecture 22 - Ecology of the Biosphere

Advance reading: Chapter 34, Campbell, Mitchell and Reece, pp. 678-697.

Objectives: In this lecture, students learn some of the characteristics of earth's biomes

CK Sequence links: Plant and Plant Growth [Gr.K§I, p. 19], Habitats [Gr.1§I.A, p. 37], Oceans and Undersea Life [Gr.1§I.B, p. 37], Science Biographies: Rachel Carson [Gr.1§VIII, p. 39], Seasonal Cycles [Gr.2§I.A, p. 59], Ecology [Gr.3§V, p. 83], Oceans: Marine Life [Gr.6§II, p. 153].

Earth biomes

There are a number of terms that students must learn as a basis for discussing the field of ecology, and these include populations (discussed in a previous lecture in the context of population genetics), communities, ecosystems, and the biosphere. The terms habitat and niche should also be defined, although they will be used more frequently in later lectures. Ecologists draw a distinction between the biotic and abiotic factors in an ecosystem, and these are also readily defined. Students should understand the unevenness of solar radiation striking the earth, and the basis for seasonal climate change.

Students should know about major earth biomes the characteristic flora and fauna in each, the range of temperature, water, and light conditions, and their approximate geographical locations. These biomes include:

- Oceans and salt marshes, pelagic and benthic zones, and tidal areas;
- Freshwater streams, lakes and marshes
- Tropical, deciduous and coniferous forests
- Temperate grasslands and savannas
- Deserts
- Arctic and alpine tundra

Elementary school teachers must carry a wealth of information about these biomes, because they are settings for many examples of childrens' literature. The children, not having visited any of these types of exotic places, may justifiably press the teacher for additional details about the places they have studied. What is the weather like there? Does it rain very often? What types of animals live there and what do they eat? Where do we find these places on a map? This can be a winning moment for the teacher, an opportunity to give the children the knowledge they seek, or a disappointment for all if the teacher cannot answer any questions.

The reading assignment

Chapter 35, Campbell, Mitchell and Reece, pp. 698-713

Laboratory 11 - Water movement

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual*, 5th Edition. pp. 129-132

Objectives: In this laboratory, students learn about transpiration in plants, and the processes of osmosis and active transport.

CK Sequence Links: Plant and Plant Growth [Gr.K§I, p. 19], Seasonal Cycles [Gr.2§I.A, p. 59], Plants: (Non-vascular and Vascular [Gr.5§III.A, p. 127]).

Just as large animals have mechanisms for circulation, vascular plants have similar problems of servicing all cells with water, minerals, and nutrients. Plants have no "heart" to pump fluids of course, so the movement of liquids and solutes is based on more subtle effects such as transpiration, active transport, and osmosis. In this laboratory, the effects of water and solute movement are studied, and many of these activities are easily adapted to the elementary or middle school classroom.

Outline - water and solute transport in plants

I. Osmosis in plant cells

II. Active transport

III. Stomata regulation

IV. Transpiration

A. Root pressure

B. Water cohesion

C. Transpiration rate

Lecture 23 - Population Dynamics

Advance reading: Chapter 35, Campbell, Mitchell and Reece, pp. 698-713.

Objectives: In this lecture, students learn the fundamental principles of ecology

CK Sequence links: Habitats [Gr.1§I.A, p. 37], Ecology [Gr.3§V, p. 83].

Birth, death, immigration and emigration

Changes in population size are due to changes in the rates of birth, death, and/or migration in and out of the group. While this is stated simply, each of these factors is extremely complex.

Students should understand the idealized model of exponential growth of a population, and the way in which populations are limited by the carrying capacity of an environment. A population consists of a number of individuals, but their density over an area of land or volume of water may be either uniform or dispersed. It is important to distinguish between density-dependent and independent factors (such as food supply and climate, respectively) and the effect that each might have on limiting population size.

Ecologists use a variety of methods to determine the sizes of populations and study their dynamics. Students may be familiar with the practice of "banding" birds with a numbered band, an identifier that is recorded each time the bird is captured in a study. They may also know about the counting of organisms in sample plots or standard sections. One important concept is that of exponential growth, or doubling times. Bacterial growth is often taken as the example, since it is so rapid and readily demonstrates the presence of population-limiting factors. In the steady-state, an environment will have a particular "carrying capacity" for a population. This is the number of individuals that the environment can maintain.

The reading assignment

Chapter 36, Campbell, Mitchell and Reece, pp. 714-735

Lecture 24 - Communities and Ecosystems

Advance reading: Chapter 36, Campbell, Mitchell and Reece, pp. 714-735.

Objectives: In this lecture, students learn how populations of individual species interact in communities and ecosystems.

CK Sequence links: Habitats [Gr.1§I.A, p. 37], Environmental Change [Gr.1§I.C, p. 37], Ecology [Gr.3§V, p. 83].

The community

Communities of organisms are characterized by the populations that comprise them, and these may be described by their number (the species richness or diversity) and by the relative size of each population element. In addition, the trophic structure, primary vegetation, and stability are factors that are useful in discussing a community. For example, the ecological succession seen after a forest fire is often discussed in the context of community stability.

Students should learn about the concept of interspecies competition and niche, and the idea behind competitive exclusion. These are idealized models of how populations interact, and competition is difficult to define experimentally. Predation is an easily understood "interaction" between two populations, but the steps that prey organisms take to avoid becoming a meal may be extremely complex. Students should know about common examples of mechanical and chemical defenses, as well as methods of mimicry, trickery, and camouflage. Food chains are founded by autotrophs (producers) in a community, and extended by primary and higher-order consumers. These chains represent the transfer of matter and energy between trophic levels, and are more accurately described as food webs. At every step of the web, some energy is lost to the environment as heat and other energy re-enters the web by the activity of decomposers. The elements carbon, nitrogen, and phosphorus re-enter the environment and are recycled.

Students have previously learned about lichens, which are an example of symbiosis between a fungus and alga, and additional examples of mutualism, commensalism and parasitism can be discussed.

The reading assignment

Chapter 37, Campbell, Mitchell and Reece, pp. 736-761

Laboratory 12 - Ecology

Advance reading: Wachtmeister & Scott. *Encounters with Life: General Biology Laboratory Manual*, 5th Edition. pp. 329-336

Objectives: In this laboratory, students learn to define the terms used in ecology, and the flow of energy through an example of an ecosystem.

CK Sequence links: Habitats [Gr.1§I.A, p. 37], Environmental Change [Gr.1§I.C, p. 37], Ecology [Gr.3§V, p. 83].

As intellectual leaders in the classroom, elementary and middle school teachers are expected to know the lore of environmental science and natural history. One field experience will not suffice to fill a substantial gap in knowledge, but may provide teachers with a sense of the methods of analysis commonly used. They may then read further in field guides, sharpening their skills of identification and their knowledge base about the local ecosystems.

The implementation of this lab will depend upon the ecosystems that may be studied on campus, or within "field trip" range. Potential areas of study for the class may include:

- Forest ecosystem
- Grassland ecosystem
- Lake, marsh, or seashore ecosystem

For any ecosystem studied by the class, the topics of analysis and discussion should include:

- Definition of the ecosystem
- Trophic levels
- Succession

Lecture 25 - Behavior

Advance reading: Chapter 37, Campbell, Mitchell and Reece, pp. 736-761.

Objectives: In this lecture, students learn about a specific type of adaptation of animals - their behavior.

CK Sequence links: Animals and Their Needs [Gr.K§II, p. 19], Science Biographies: Goodall [Gr.K§VII, p. 20], Seasonal Cycles [Gr.2§I.A, p. 59], Insects [Gr.2§II, p. 59].

Behavioral adaptations

A discussion of animal behavior may start with examples of genetically programmed and learned behaviors. The genetically programmed types may be characterized as "fixed action patterns," and in some cases the cues that trigger them can be generated in an experimental setting. Learned behaviors may have some component of innate behavior, such as in the case of imprinting. Migration behaviors are often mixtures of learned and genetically-programmed components, and are important to discuss. Some types of learned behaviors are characterized as conditioned, based on either positive or negative reinforcement, and other types are said to be learning by imitation or innovation. These are all idealized concepts, and actual behavioral patterns may be a mixture of different "types."

Students should learn about common behaviors such as territorial aggression, mating rituals, dominance hierarchies, and altruism. The social organization of certain insects (such as bees and ants) is a topic of extensive research, and provides many examples for discussion.

This being the last lecture in the series, some time might be set aside for review and course completion.

Introductory Biology - Sample Midterm Examination (Lectures 1-11)

50 problems

Cell biology

1. All bacteria are classified as:

   A. Eukaryotic

   B. Prokaryotic

   C. Pathogenic

   D. Parasitic

2. Ribosomes perform the function of:

   A. Assembling amino acids into polypeptides

   B. Removing or isolating cellular wastes

   C. Propelling a cell through its environment

   D. Synthesis of lipids, including fatty acids

3. The function of the Golgi apparatus is:

   A. Providing structural support for cells through interlocking filaments

   B. Breaking down injested bacteria through release of hydrolytic enzymes

   C. Anchoring cells to each other (e.g. in an epithelial sheet)

   D. Receiving and modifying proteins from the endoplasmic reticulum

4. Chloroplasts have structures called grana that:

   A. Are partly responsible for converting light energy to chemical energy

   B. Convert simple sugars to carbon dioxide and water

   C. Convert chlorophyll molecules to oxygen, NADPH, and ATP

   D. Perform the Calvin Cycle

5. In a eukaryotic cell, microtubules:

   A. Are composed of globular proteins called tubulins

   B. Provide anchorage for organelles

C. Guide the movement of chromosomes

D. All of the above

Cellular processes and enzymes

6. According to the First Law of Thermodynamics:

A. A cell cannot convert sugar "fuel" to energy with 100% efficiency

B. The total amount of energy in the universe is constant

C. The level of disorder in the universe is increasing

D. Energy is the capacity to do work

7. An endergonic reaction is one:

A. Requiring cellular respiration

B. In which work is performed

C. In which net heat is generated

D. Requiring a net input of energy

8. An enzyme acts as a catalyst by:

A. Increasing the rate of a reaction

B. Increasing the energy of activation of a reaction

C. Decreasing the net change in energy of a reaction

D. All of the above

9. Diffusion of water across a semipermeable membrane is called:

A. Active transport

B. Osmosis

C. Facilitated diffusion

D. Endocytosis

10. An inhibitor that interferes with an enzyme by resembling its normal substrate is called a:

A. Noncompetitive inhibitor

B. Competitive inhibitor

C. Feedback inhibitor

D. Catalyst

Mitochondria and energetics

11. What is the efficiency with which yeast cells harvest energy from glucose in an anaerobic environment? (assume 100% of the energy could be obtained by burning the same glucose in a fire)

A. 100%

B. 20%

C. 10%

D. 2%

12. In the harvesting of energy from glucose during respiration, the three main stages are (in chronological order):

A. Krebs cycle, Electron transport chain, Glycolysis

B. Krebs cycle, Glycolysis, Electron transport chain

C. Glycolysis, Krebs cycle, Electron transport chain

D. Glycolysis, Electron transport chain, Krebs cycle,

13. During the Krebs cycle, how many carbon dioxide molecules are generated for each acetyl-CoA introduced (each "turn" of the cycle)?

A. One

B. Two

C. Three

D. Four

14. During aerobic respiration, about 36 molecules of ATP are generated per glucose molecule, and most of these are generated during the:

A. Fermentation stage

B. Krebs cycle

C. Process of glycolysis

D. Electron transport chain and chemiosmosis stage

15. During strenuous exercise, human muscle cells produce:

A. Ethanol

B. Lactic acid

C. Glucose

D. Oxygen

Photosynthesis

16. Carbon dioxide enters the leaves of a vascular plant by means of tiny pores called:

    A. Stomata

    B. Porins

    C. Grana

    D. Chloroplasts

17. The "light reactions" of photosynthesis are characterized by:

    A. One turn of the Calvin cycle

    B. The fixation of carbon dioxide

    C. The conversion of light energy to chemical energy

    D. All of the above

18. Oxygen is generated during photosynthesis by the splitting of:

    A. Chlorophyll

    B. Carbon dioxide

    C. Photons

    D. Water

19. In comparison to C3 plants, the C4 plants have adaptations that:

    A. Allow photorespiration in severe environmental conditions

    B. Allow rubisco to fix oxygen in the Calvin cycle

    C. Allow continued photosynthesis in hot and dry weather

    D. Allow carbon fixation outside of chloroplasts

20. In the electron transport chain of chloroplasts, a chemiosmotic gradient is generated by translocation of:

    A. ATP

    B. Protons

    C. Electrons

    D. Oxygen

Mitosis and somatic cell genetics

21. In the eukaryotic cell cycle, the four main stages are (in chronological order):

A. G1, S, G2, and mitosis

B. S, G1, G2, and mitosis

C. G1, mitosis, G2, and S

D. G1, S, mitosis, and G2

22. During the process of cytokinesis in eukaryotic cells:

A. The chromosomes condense and become associated with the mitotic spindle

B. The sister chromatids are aligned along a metaphase plate

C. The chromosomes are replicated

D. The cytoplasm is divided

23. Which of the following cell types are capable of undergoing meiosis:

A. Germ cells in testes and ovaries

B. Onion root tip cells

C. Malignant tumor cells

D. All of the above

24. A cell that is diploid:

A. Is also called a zygote

B. Has completed the second stage of meiosis

C. Has two copies of each autosome

D. Has an arrested cell cycle

25. Two chromosomes that are "homologous" typically carry:

A. Exactly the same DNA sequence

B. Different versions of the same genes

C. The same genes in a different order

D. Different genes at the same corresponding loci

Mendelian genetics

26. Mendel's "true-breeding" varieties of peas:

A. Produced offspring identical to the parent upon self-fertilization

B. Produced hybrid offspring through cross-fertilization

C. Contained only dominant alleles

D. Maintained high levels of reproductive fitness in F1 and F2 generations

27. In a monohybrid cross between purple (PP) and white (pp) flowered peas, where P is a dominant allele and p recessive, what is the expected fraction of white-flowered peas in the F1 generation?

A. 0.0

B. 0.25

C. 0.5

D. 0.75

28. Alleles of genes that map to distinct loci:

A. Usually result in a state of codominance

B. Are linked genes

C. Segregate in a ratio of 1:2:1 upon self-fertilization (in plants)

D. Typically assort independently during gamete formation

29. When red (RR) snapdragons are crossed with white (rr) snapdragons, all the F1 generation flowers are pink. This serves as an example of:

A. Independent assortment

B. Incomplete dominance

C. Crossing over

D. Pleiotropy

30. A gene on the human X chromosome is **never** passed genetically:

A. From father to son

B. From mother to daughter

C. From mother to son

D. Father to daughter

Molecular biology

31. Which one of these base-pairs does **not** found in nucleic acids??

A. A base-paired with T

B. C base-paired with G

C. C base-paired with T

D. A base-paired with U

32. In gene expression, the two main stages are (in chronological order):

A. Transcription and translation

B. Transcription and ligation

C. Ligation and translation

D. Translation and transcription

33. Both UUU and UUC encode phenylalanine in the genetic code, an example of:

A. Reading frame

B. Degeneracy

C. Transcription

D. Translocation

34. The variety of specialized cells in humans (e.g. nerve vs muscle cells) is a direct result of:

A. Independent gene assortment at mitosis

B. Crossing over

C. Differential gene expression

D. Nuclear transplantation

35. In eukaryotic cells, transcription takes place in:

A. Membrane-bound ribosomes

B. The nucleus

C. The endoplasmic reticulum

D. None of the above

Genetics of populations

36. Genetic variation is caused by:

A. Nucleotide substitution in DNA

B. Chromosome shuffling by sexual recombination

C. Crossing-over during meiosis

D. All of the above

37. Which of these is **not** a potential cause of microevolution in a population?

A. Genetic drift

B. Random mating

C. Founder effect

D. Mutation

38. Natural selection does not typically make populations genetically uniform, because:

A. The effects of recessive alleles are not displayed in heterozygotes

B. Some genes have a "heterozygote advantage"

C. The gene pool remains susceptible to new mutations

D. <u>All of the above</u>

39. The evolutionary fitness of an individual is related to its:

A. <u>Contribution to the gene pool of the next generation</u>

B. Level of neutral variation

C. Rate of mutation

D. Environmental adaptations and the ecosystem in which it resides

40. Individuals in a population that are best-adapted to an environment

A. Do not continue to evolve

B. <u>Are more likely to survive and reproduce</u>

C. Are in a state of Hardy-Weinberg equilibrium

D. Always have equal reproductive success

The origin of species

41. Which of these is a prezygotic barrier to reproduction?

A. <u>Behavioral isolation</u>

B. Hybrid sterility

C. Hybrid inviability

D. All of the above

42. In evolutionary biology, the Galapagos islands are an example of:

A. Temporal isolation of species

B. Gametic isolation of species

C. Hybrid breakdown of species

D. Adaptive radiation of species

43. Darwin suggested that the basic mechanism of evolution is:

A. Genetic drift

B. Natural selection

C. Habitat isolation

D. Independent segregation of genetic loci

44. Homology between structures in two organisms indicates:

A. Common ancestry

B. Convergent evolution

C. Speciation

D. Adaptation

45. In the punctuated equilibrium model of evolution:

A. Evolution occurs at regular time intervals

B. Evolution is independent of natural selection

C. Evolution occurs in short bursts of time

D. None of the above

Microbial Evolution

46. Archaebacteria and eubacteria are types of:

A. Protists

B. Prokaryotes

C. Fungi

D. Infections

47. Cyanobacteria are:

A. <u>Photosynthetic</u>

B. Pathogenic

C. Protozoans

D. Pseudopodia

48. Green algae may be either:

A. Prokaryotic or eukaryotic

B. <u>Unicellular or multicellular</u>

C. Plasmodial or amoeboid

D. Protozoan or bacterial

49. Which of these is **not** one of the "postulates" used by Koch to prove that a specific infectious agent is the cause of a disease

A. That the same pathogen must be identified in each host having the disease

B. That the pathogen must be isolated from a host and grown in a pure culture

C. That the original disease must be produced in experimentally inoculated hosts

D. <u>That the pathogen must be identified microscopically as a bacterium</u>

50. Mitochondria and chloroplasts are organelles thought to have originated through:

A. Endospore disintegration

B. Eukaryotic differentiation

C. <u>Endosymbiosis</u>

D. Colonization

Introductory Biology - Sample Final Examination (Lectures 12-25)

Plant and Animal Diversity

1. Land plants frequently have a cuticle covering that:

   A. <u>Prevents water loss</u>

   B. Extracts nitrogen from the soil

   C. Produces oxygen

   D. Contains dividing cells

2. Sporophyte and gametophyte life cycle stages are characteristic of which of these plants?

   A. Bryophytes

   B. Gymnosperms

   C. Angiosperms

   D. <u>All of the above</u>

3. We have learned that the structure of a fruit reflects its function in seed dispersal. Provide an example of this principle, and explain how the example illustrates the concept. (Short answer)

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4. Which of these animals does **not** have a body plan based on bilateral symmetry?

   A. Tapeworm

   B. <u>Sea anemone</u>

   C. Lobster

   D. Human

5. Which of these is **not** a feature of echinoderms?

A. Body segmentation

B. Endoskeleton

C. Water vascular system

D. Regeneration

Animal Physiology

6. In our small intestine, the absorption of nutrients is facilitated by structures called:

A. Longitudinal muscles

B. Gastric glands

C. Villi

D. None of the above

7. Blood pumped from the right ventricle of our hearts would next be found in the:

A. Right atrium

B. Pulmonary artery

C. Aorta

D. Left ventricle

8. We have learned that the different structures of blood vessels reflect their function. Explain how smooth muscle and connective tissue layers have a function in large arteries near the heart. (Short answer)

9. Which of these is **not** a function of antibodies?

A. Agglutination of bacteria

B. Neutralization of viruses

C. Precipitation of antigens

D. Protection from phagocytosis

10. Urine leaves a kidney and is voided from the body by what pathway?

A. <u>Ureter to urinary bladder to urethra</u>

B. Urinary bladder to nephron tubule to collecting duct

C. Renal vein to urethra to urinary bladder

D. None of the above

11. Gastrulation during embryogenesis leads to the sorting of cells into:

A. <u>Ectoderm, endoderm and mesoderm layers</u>

B. Blastula, archenteron and yolk plug

C. Neural plate and neural tube

D. Somites

12. Chains of Schwann cells form a layer around motor neurons that is called a:

A. Node of Ranvier

B. Synaptic knob

C. <u>Myelin sheath</u>

D. Axon

13. Briefly describe the structures and functions of the parts of the inner ear. (Short answer)

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14. Explain how the circular muscles and external bristles of an earthworm are used during crawling locomotion (Short answer)

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15. Animals that have an exoskeleton typically also:

A. <u>Undergo molting</u>

B. Are aquatic

C. Have radial symmetry

D. Have a vertebrate body plan

16. Compare and contrast the structures and functions of ball and socket joints and hinge joints. (Extended answer, may include carefully-labeled diagrams)

Plant form and function

17. Which of these structures are **not** found in angiosperms:

A. Xylem

B. Root hairs

C. Cones

D. Cotyledons

18. Pollen germination is followed by what process in flowering plants?

A. Fertilization

B. Pollination

C. Meiosis

D. Ovulation

19. The flow of water from the roots to leaves of a plant is called:

A. Expiration

B. Translocation

C. Exfoliation

D. Transpiration

20. Explain briefly how deciduous trees lose their leaves each autumn (Short answer)

Ecology

21. The carrying capacity of an environment is best described as:

A. The intrinsic rate of increase in population size

B. The number of individuals that can be maintained steadily in a population

C. The ability of the population to grow without bounds

D. The age structure of its populations.

22. Provide three examples of abiotic factors and explain how organisms may adapt to them in an ecosystem (Extended answer)

23. Provide a specific example of an adaptation in a plant or animal that may limit predation (Short answer)

24. Which of these disturbances might lead to primary succession in a community?

A. A tree falling in a forest

B. A volcanic eruption

C. A high rate of predation

D. An early winter

25. Provide an example of a learned behavior that reflects habituation (Short answer)

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Appendix A: Collation of Two Textbooks

Campbell, Mitchell, and Reece	Audesirk and Audesirk
1. Introduction: The Scientific Study of Life.	1. An Introduction to Life on Earth.
I. THE LIFE OF THE CELL.	I. THE LIFE OF A CELL.
2. The Chemical Basis of Life.	2. Atoms, Molecules, and Life.
3. The Molecules of Cells.	3. Energy Flow in the Life of a Cell.
4. A Tour of the Cell.	4. Cell Membrane Structure and Function.
5. The Working Cell.	5. Cell Structure and Function.
6. How Cells Harvest Chemical Energy.	6. Capturing Solar Energy: Photosynthesis.
7: Photosynthesis: Using Light to Make Food.	7. Harvesting Energy: Glycolysis and Cellular F
II. CELLULAR REPRODUCTION AND GENETICS.	II. INHERITANCE.
8. The Cellular Basis of Reproduction and Inheritance.	8. DNA: The Molecule of Heredity.
9. Patterns of Inheritance.	9. Gene Expression and Regulation.
10. Molecular Biology of the Gene.	10. The Continuity of Life: Cellular Reproductio
11. The Control of Gene Expression.	11. Patterns of Inheritance.
12. DNA Technology and the Human Genome.	12. Biotechnology.
III. CONCEPTS OF EVOLUTION.	III. EVOLUTION.
13. How Populations Evolve.	13. Principles of Evolution.
14. The Origin of Species.	14. How Organisms Evolve.
15. Tracing Evolutionary History.	15. The History of Life on Earth.
IV. THE EVOLUTION OF BIOLOGICAL DIVERSITY.	16. The Diversity of Life.
16. The Origin and Evolution of Microbial Life: Prokaryotes and Protists.	
17. Plants, Fungi, and the Colonization of Land.	IV. PLANT ANATOMY AND PHYSIOLOGY.
18. The Evolution of Animal Diversity.	17. Plant Form and Function.
19. Human Evolution. V.	18. Plant Responses to the Environment.
ANIMALS: FORM AND FUNCTION.	V. ANIMAL ANATOMY AND PHYSIOLOGY.
20. Unifying Concepts of Animal Structure and Function.	19. Homeostasis and the Organization of the A
21. Nutrition and Digestion.	20. Circulation and Respiration.
22. Respiration: The Exchange of Gases.	21. Nutrition, Digestion, and Excretion.
23. Circulation.	22. Defenses Against Disease: The Immune R
24. The Immune System.	23. Chemical Control of the Animal Body: The
25. Control of the Internal Environment.	24. The Nervous System and the Senses.
26. Chemical Regulation.	25. Animal Reproduction and Development.
27. Reproduction and Embryonic Development.	26. Animal Behavior.
28. Nervous Systems.	
29. The Senses.	
30. How Animals Move.	
VI. PLANTS: FORM AND FUNCTION.	
31. Plant Structure, Reproduction, and Development.	
32. Plant Nutrition and Transport.	
33. Control Systems in Plants.	
VII. ECOLOGY.	VI. ECOLOGY.

34. The Biosphere: An Introduction to Earth's Diverse Environments. 35. Population Dynamics. 36. Communities and Ecosystems. 37. Behavioral Adaptations to the Environment. 38. Conservation Biology.	27. Population Growth and Regulation. 28. Community Interactions. 29. How Do Ecosystems Work? 30. Earth's Diverse Ecosystems.