The Learning Framework endorsed by the American Physiological Society Center for Physiology Education Advisory Board for CourseSource are the core concepts of physiology developed and revised by [Michael and McFarland, 2020](https://journals.physiology.org/doi/epdf/10.1152/advan.00114.2020).

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| **Core Concept & Definition** | **Core Concept****Explanation** | **Learning Goal** | **Sample** **Learning Objectives** |
| **Cell-Cell Communication***In a living organism, cells must pass information to one another to coordinate their activities.* | Cells communicate with one another using different mechanisms: generation and transport of endocrine signals, generation and transmission of neural (electrical) signals, and cell-cell contact. | How do cells send and receive signals from each other to coordinate cell, tissue, organ and system physiology? | * Compare and contrast steroid hormones and water-soluble hormones for their generation, transport, and mechanism of action on target cells
* Draw different feedback mechanisms that regulate endocrine signaling to maintain homeostasis
* Describe the different mechanisms by which neural cells transmit electrical signals to other cells influencing their physiology
* Predict the outcomes on cell, tissue and organ physiology of interrupting cell-cell communication mechanisms
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| **Cell Membrane***Cell plasma membranes are complex structures that determine what, and how, substances enter or leave the cell. Cell membranes also play an important role in generating and receiving signals from each other.* | Every cell has a membrane separating the constituents of the cell from the extracellular compartment, and in general, from other cells.Every physiological phenomenon (function) ultimately depends on the behavior of cells and their membranes. | How do cell membranes support transport and communication between intracellular and extracellular environments? | * Identify cell membrane components and describe how their structures relate to their functions with regard to communication and transport
* Describe how the structure of the cell membrane establishes resting membrane potential and apply the Nernst equation to determine membrane potential given intracellular and extracellular concentrations of certain ions
* Identify extracellular compartments between cells within the same tissue, organ, system and across different body systems
* Explain how alterations in membrane potential result in changes in physiology in excitable tissues containing neural cells and muscles as well as in non-excitable tissues
* Predict how changes in cell membrane structure and cell surface receptor composition result in physiological changes and possible cellular disorders
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| **Cell Theory***All cells arise from other cells and, thus, have the same DNA as their parent cell. All cells making up the organism have the same DNA. Cells have many functions in common, but cells also have many specialized functions that are required by the organism.* | Cell theory is one of the oldest concepts in modern biology. Although physiology students are introduced to this concept in other biology courses, it has physiological implications that may not be obvious to students. | How do cells produce other cells via different mechanisms to generate tissues, organs, and systems that maintain physiological function within an organism and ensuring generation of its progeny? | * Describe how cell theory relates to cell division and organismal growth
* Compare and contrast the processes and locations of mitotic and meiotic cell division
* Predict the effects on the physiology of cells, tissues, organs and systems of an abnormal event that occurs during the mitotic or meiotic cell division cycle
* Explain the theories of tissue regeneration using adult stem cells that differentiate, replenish themselves, and age
* Distinguish the effects of cell division, differentiation, aging, and death on the establishment and maintenance of physiological function within tissues, organs, and systems
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| **Energy***The maintenance of the life of the organism requires the constant expenditure of energy. The acquisition, transformation, and transportation of energy are essential functions of the body.* | Ingestion of food, digestion, and the generation of ATP (the energy source for most biological processes) are steps in the process of providing every cell with the energy needed to function and survive.Students are introduced to this concept in other biology and science courses and should be able to apply it to physiological processes.  | How do organisms acquire, transform, and transport energy? | * Explain why cells and organisms require energy
* Explain how ATP hydrolysis and ion gradients provide energy to power cellular processes
* Trace the path of energy transformation from the intake of food to the production of ATP in the cell
* Predict what may occur to cellular and organismal function if energy availability is disrupted
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| **Evolution***Evolution is genetic change within a population over time. Three mechanisms drive this change: variation (gene mutation), inheritance, and selection.* | Living organisms share a common ancestor, and the process of evolution has resulted in the present-day variety of species. The mechanisms of evolution act at many levels of organization and result in adaptive changes that have produced the extant relationships between biological structure and physiological function. This concept is often not addressed in physiology courses; however, students are introduced to the concept of evolution in other biology courses. | How does evolutionary history explain the relationship between biological structure and physiological function? | * Explain how variation, inheritance, and selection drive the evolution of anatomical structures and physiological functions
* Explain how anatomical form and function relationships and physiological systems exist as evolutionary trade-offs
* Describe two or more physical traits that multiple organisms share and how differences in structure can shape physiological function in relation to each organism’s environment
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| **Flow Down Gradients (Flux)***The transport of “stuff” (ions, molecules, fluids, and gas) is a central process at all levels of organization in the organism, and a simple model describes such transport.* | Ions or other solutes crossing a cell membrane, blood flowing in blood vessels, gas flowing in airways, and chyme moving down the gastrointestinal tract are all processes that result from the interaction of an energy gradient and the resistance to flow that is present. It is likely that students have encountered this concept in previous science courses, but they need help to transfer that understanding to physiology. This core concept does not incorporate active transport mechanisms.  | How do ions, molecules, fluids, and gases flow down gradients? | * Compare and contrast pressure, chemical, electrical, and electrochemical gradients
* Explain the physiological impacts of molecules, ions, fluids, or gases flowing down gradients
* Explain the roles that gradients and resistance to flow contribute to the flow or flux of molecules, ions, fluids, and gases
* Predict the direction of flow of an ion, molecule, fluid, or gas given a gradient
* Predict how changes in resistance affect flow down gradients of ions, molecules, fluids, and gases
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| **Genes to Proteins***The genes (DNA) of every organism code for, and contain information needed for, the synthesis of proteins (enzymes and structural proteins). The genes that are expressed in a cell determine the structure and functions of that cell.* | This is the central dogma of molecular biology, and it explains both the development of the individual organism from a fertilized ovum, as well as changes that occur in the function and structure of organisms throughout life. Students are introduced to the central dogma in other biology courses. Although this concept may not be addressed explicitly in many physiology courses, students should be able to apply it in the context of physiology. | How does transcription of DNA to RNA and protein translation contribute to the structural anatomical and physiological function of an organism? | * Explain how RNA is transcribed from DNA and how protein is translated from RNA
* Explain the different mechanisms by which gene expression is regulated
* Compare and contrast epigenetic and genetic mechanisms that transmit anatomical and physiological information during cellular division and organismal reproduction
* Predict how alterations in gene expression may affect anatomical and physiological traits of an organism
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| **Homeostasis***The internal environment of the organism is actively maintained more or less constant by the function of cells, tissues, and organs organized into negative feedback systems.* | The role of negative feedback in regulating the functions of the body is a particularly powerful core concept, in that it describes so much of organ system physiology. We have limited this core concept to a description of negative feedback systems, although we recognized that there are a number of other kinds of control mechanisms that contribute to determining system function.  | How does the internal environment of the organism maintain homeostasis via negative feedback systems? | * Give examples of negative feedback from each body system and how it works at the levels of cells, tissues, and/or organs.
* Describe how perturbations to homeostasis are detected by sensors in the body and acted upon in an attempt to restore homeostasis
* Draw and label a negative feedback system for a single body system and for integration across multiple body systems
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| **Levels of Organization***Understanding physiological functions requires understanding the behavior of entities at every level of organization in the organism from the molecules to organ systems and on to society and the environment.* | To understand physiological phenomena and solve problems in physiology, it is necessary to determine at what organizational level(s)an answer is to be found. Students need frequent opportunities to apply this core conceptin all physiological contexts. | What biological organizational levels exist in an organism and why is this important? | * Describe the different levels of biological organization
* Describe the relationship between anatomy and physiology and how they influence each other in different levels of organization
* Compare and contrast the organizational levels of different organ systems in animals and plants

* Describe and analyze examples of emergent properties that arise at each level of organization
* Evaluate and critique the limitations of reductionism in biology and the need for a holistic approach that considers multiple levels of organization from molecular to societal in problem solving
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| **Mass Balance***The contents of any system, or compartment in a system, is determined by the inputs to and the outputs from that system or compartment. This simple general model of rates-in and rates-out applies to all physical systems.* | Mass (or matter) can be liquid (e.g., water, blood), gas (e.g., oxygen, carbon dioxide), solute within a liquid medium (e.g., ions, glucose, hormones), or solid (e.g., CaPO4 in bone). The region of interest may be considered to be a compartment with, potentially, multiple entry and exit paths. The quantity of mass within a compartment depends on the initial quantity of mass in the compartment, the rate of entry of mass into the compartment, and the rate of exit of mass from the compartment.  | How do mass balances (in and out) affect biological systems? | * Build a model to describe the ways that mass can enter or exit a physiological system
* Explain the factors that contribute to the amount of mass changing within a physiological system
* Construct a mass balance on a physiological system and determine if there is net mass moving in to or out of the system
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| **Physical Properties of Matter***Living organisms are physical systems and their functions are explainable by the application of the laws of physics and chemistry. Living organisms are causal mechanisms (machines) whose functions are explainable by a description of the cause-and-effect relationships that are present.* | The functions of the body arise from the interaction of atoms, ions, and molecules, as described by the laws of chemistry and physics. A consideration of the physical properties of biological systems (elasticity, capacitance, viscosity etc.) is necessary to understand of physiological phenomena. Thus, an “explanation” for a physiological phenomenon or mechanism must include a set of statements outlining the cause-and- effect relationships (the causal relationships) between entities.  | How do physical properties of matter contribute to living organisms? | * Describe the types of matter that are found in physiological systems
* Explain how basic laws of chemistry and physics to apply to physiological systems
* Predict how a physiological system may change given perturbations depending on the laws of chemistry and physics
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| **Scientific Reasoning***Physiology is a science.**Our understanding of the functions of the body arises from the application of the processes of science, including the scientific method; thus, our understanding is always tentative. It is scientific reasoning using inference, information literacy, observations, study design, data analysis and interpretation that has generated the information that fills our textbooks. To fully understand physiology, one must understand how the results were generated and how future results will be generated.* | Students are introduced to this core concept in other science courses. If this concept is a part of a physiology course or curriculum, it is usually taught as a discrete topic to be mastered by the students. However, this concept should be explicitly addressed in all physiology courses.  | How have experimental designs in physiology informed our understanding of physiological concepts? | * Explain how scientific reasoning is applied to the study of anatomy and physiology
* Give an example of an experiment that led to a key discovery in physiology, including the study methods, results, and interpretations
* Describe multiple experimental methods to measure shifts in physiological phenomena in a given system, as well as the limitations of these methods.
* Design an experiment to investigate the impact of structural or environmental changes on the function of an organism
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| **Structure ↔ Function***Structure and function (from the molecular level to the organ system level) are intrinsically related to each other.* *The functions of molecules, cells, tissues, or organs are determined by their form (structure), and function can alter structure. (The change in the connecting symbol is intended to indicate the bidirectionality of the relationship between structure and function.)* | This core concept is commonly used in two different ways: large-scale and molecular. Diffusion between body compartments ismaximized when the surface area available is large and the diffusion distance is small. There are other such macroscale phenomena where the structure of the system makes possible the function of that system. However, on a molecular scale, the structure of proteins like hemoglobin and enzymes determine their function, and changes in those structures alter their function in important ways.  | How does the structure of any part of the organism, from the cellular to organism level, contribute to the function of the organism? | * Describe the structural similarities found across systems and taxa that support a similar function
* Given a specific physiological system, describe the structural adaptations that contribute to the system’s function
* Predict how changes in environmental or pathological conditions can affect the structure and functional of biological systems
* Given a pathological scenario, predict how the changes in structure impact the function of the relevant physiological system
* Distinguish between normal variation that supports function and structural variations associated with pathology
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| **Systems Integration***Organ systems work together; understanding the functions of the organism require a consideration of how multiple entities (cell, tissues, organs, and organ systems) interact with one another to sustain the life of the organism.* | Physiology is typically studied and taught one organ system at a time. It is particularly important that students be given opportunities to address physiological phenomena and solve problems that require them to apply their knowledge of several systems at the same time.  | How do systems interact and communicate with one another to maintain the organism's overall balance? | * Describe specific examples of physiological systems integration in action
* Predict how changes in one system may impact the function of others.
* Create models of the connections between different anatomical and physiological systems
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