

# Supplemental Material

*CBE—Life Sciences Education*

Brownell *et al.*

Major Sub-disciplines of Biology						
Molecular/ Cellular/ Developmental Biology		Physiology		Ecology/ Evolutionary Biology		
<b>EVOLUTION</b>	<b>Overarching Principles:</b> <i>Evolution is a change in allele frequencies caused by mutations, natural selection, gene flow, or genetic drift. Populations can diverge, leading to the formation of new species.</i> <i>Mutations are changes in DNA that occur at random in every generation in every population. Natural selection occurs when individuals with certain heritable traits have higher reproductive success than individuals without those traits. Genetic drift occurs when allele frequencies change by chance.</i>					
	Importance for graduating biology major			Scientific accuracy		
	3.82 (0.04)			3.55 (0.05)		
	SA: 85.9% A: 12.5% D: 0% SD: 1.6%			SA: 60.9% A: 35.3% D: 2.2% SD: 1.6%		
	<i>Multiple molecular mechanisms, including DNA damage and errors in replication, lead to the generation of random mutations. These mutations create new alleles that can be inherited via mitosis (through asexual reproduction) or meiosis (through sexual reproduction).</i>		Mutations that change protein structure and/or regulation can impact anatomy and physiological function at all levels of organization.		The characteristics of populations change over time due to changes in allele frequencies. Changes in allele frequencies are caused by random and nonrandom processes--specifically mutation, natural selection, gene flow, and genetic drift. Not all of these changes are adaptive.	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
	3.79 (0.04)	3.58 (0.05)	3.73 (0.04)	3.65 (0.04)	3.81 (0.03)	3.72 (0.04)
	SA: 81.5% A: 16.9% D: 0.5% SD: 1.1%	SA: 64.1% A: 31.5% D: 2.7% SD: 1.6%	SA: 75% A: 22.8% D: 2.2% SD: 0%	SA: 70.1% A: 25.5% D: 3.8% SD: 0.5%	SA: 81.0% A: 19.0% D: 0% SD: 0%	SA: 73.4% A: 25.0% D: 1.6% SD: 0%
	Mutations and epigenetic modifications can impact the regulation of gene expression and/or the structure and function of the gene product. If mutations affect phenotype and lead to increased reproductive success, the frequency of those alleles will increase in the population.		<i>Most organisms have anatomical and physiological traits that maximize their fitness for a particular environment.</i>		All species alive today are derived from the same common ancestor. New species arise when populations become genetically isolated and diverge due to mutation, selection, and drift. Phylogenetic trees depict relationships among ancestral and descendant species, and are estimated based on data.	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
3.77 (0.03)	3.60 (0.04)	3.50 (0.05)	3.27 (0.06)	3.73 (0.04)	3.55 (0.05)	
SA: 78.3% A: 20.7% D: 1.1% SD: 0%	SA: 63.6% A: 33.1% D: 3.26% SD: 0%	SA: 60.3% A: 31.0% D: 7.6% SD: 1.1%	SA: 46.7% A: 35.9% D: 15.2% SD: 2.2%	SA: 77.2% A: 19.6% D: 2.2% SD: 1.1%	SA: 63.0% A: 30.4% D: 4.9% SD: 1.6%	
		Physiological systems are constrained by ancestral structures, physical limits, and the requirements of other physiological systems, leading to trade-offs that affect fitness.		Fitness is an individual's ability to survive and reproduce. It is environment-specific and depends on both abiotic and biotic factors. Natural selection's ability to optimize fitness is constrained by trade-offs, existing variation, and other factors.		
		Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	
		3.61 (0.04)	3.60 (0.05)	3.68 (0.04)	3.57 (0.05)	
		SA: 66.8% A: 28.3% D: 4.4% SD: 0.5%	SA: 66.3% A: 28.3% D: 4.9% SD: 0.5%	SA: 73.9% A: 21.7% D: 3.3% SD: 1.1%	SA: 65.2% A: 28.8% D: 3.8% SD: 2.2%	
<b>Molecules (Smaller and faster)</b>		▶		<b>Ecosystems (Larger and slower)</b>		
<b>Biological Scale</b>						

Major Sub-disciplines of Biology						
Molecular/ Cellular/ Developmental Biology		Physiology		Ecology/ Evolutionary Biology		
<b>INFORMATION FLOW</b>	<p align="center"><b>Overarching Principles:</b>  <i>Organisms inherit genetic and epigenetic information that contribute to an individual's phenotype. The timing and degree of gene expression is highly regulated, in a way that affects phenotype.</i>  <i>Cells/organs/organisms constantly monitor their internal and external environment. Perception and transmission of this information allows organisms to respond to changing conditions.</i></p>					
	Importance for graduating biology major			Scientific accuracy		
	3.74 (0.03)			3.58 (0.04)		
	SA: 75.0% A: 23.9% D: 1.1% SD: 0%			SA: 61.4% A: 35.3% D: 3.3% SD: 0%		
	In most cases, genetic information flows from DNA to mRNA to protein, but there are important exceptions.		Information stored in DNA is expressed as RNA and/or proteins that impact anatomical structures and physiological function.		Individuals transmit genetic information to their offspring; some alleles confer higher fitness than others.	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
	3.66 (0.04)	3.59 (0.04)	3.73 (0.04)	3.65 (0.04)	3.71 (0.04)	3.64 (0.04)
	SA: 69.0% A: 28.8% D: 1.6% SD: 0.5%	SA: 62.5% A: 34.8% D: 2.2% SD: 0.5%	SA: 76.6% A: 20.1% D: 2.7% SD: 0.5%	SA: 69.0% A: 27.7% D: 2.7% SD: 0.5%	SA: 72.3% A: 26.1% D: 1.6% SD: 0%	SA: 65.8% A: 32.1% D: 2.2% SD: 0%
	Gene expression and protein activity are regulated by intracellular and extracellular signaling molecules. Signal transduction pathways are crucial in relaying these signals.		Organisms have sophisticated mechanisms for sensing changes in the internal or external environment. They use chemical, electrical, or other forms of signaling to coordinate responses at the cellular, tissue, organ, and/or system level.		A genotype influences the range of possible phenotypes in an individual; the actual phenotype results from interactions between alleles and the environment.	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
3.62 (0.04)	3.69 (0.03)	3.70 (0.04)	3.72 (0.03)	3.79 (0.03)	3.70 (0.04)	
SA: 66.3% A: 29.4% D: 4.4% SD: 0%	SA: 69.0% A: 31.0% D: 0% SD: 0%	SA: 71.2% A: 27.2% D: 1.6% SD: 0%	SA: 72.3% A: 27.7% D: 0% SD: 0%	SA: 79.9% A: 19.0% D: 1.1% SD: 0%	SA: 71.7% A: 26.1% D: 2.2% SD: 0%	
The signals that a cell receives depend on its location, and change through time. As a result, different types of cells express different genes, even though they contain the same DNA.						
Importance for graduating biology major	Scientific accuracy					
3.77 (0.03)	3.64 (0.04)					
SA: 78.3% A: 20.6% D: 1.1% SD: 0%		SA: 66.3% A: 31.5% D: 2.2% SD: 0%				
<p align="center"><b>Molecules (Smaller and faster)</b></p>			▶	<p align="center"><b>Ecosystems (Larger and slower)</b></p>		
<b>Biological Scale</b>						

Major Sub-disciplines of Biology						
Molecular/ Cellular/ Developmental Biology		Physiology		Ecology/ Evolutionary Biology		
<b>STRUCTURE FUNCTION</b>	<b>Overarching Principles:</b> <i>Biological structures can be studied at all levels of organization, from molecules to ecosystems.</i>  <i>Natural selection favors the evolution of structures that maximize fitness within the context of evolutionary and environmental constraints.</i>  <i>A structure's function is a product of its physical characteristics (e.g size and chemical composition).</i>					
	Importance for graduating biology major			Scientific accuracy		
	3.71 (0.04)			3.45 (0.05)		
	SA: 73.9% A: 22.8% D: 3.3% SD: 0%			SA: 54.4% A: 37.0% D: 8.1% SD: 0.5%		
	The structure of a cell--its shape, organelles, and polarity--impacts its function.		Physiological functions are often compartmentalized into different cells, tissues, organs, and systems, which have structures that support specialized activities.		Natural selection has favored structures whose shape and composition contribute to their ecological function.	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
	3.70 (0.04)	3.64 (0.04)	3.63 (0.04)	3.64 (0.04)	3.47 (0.05)	3.38 (0.05)
	SA: 71.7% A: 26.1% D: 2.2% SD: 0%	SA: 67.4% A: 29.3% D: 3.3% SD: 0%	SA: 67.9% A: 27.2% D: 4.4% SD: 0.5%	SA: 66.3% A: 31.5% D: 1.6% SD: 0.5%	SA: 56.5% A: 35.3% D: 7.1% SD: 1.1%	SA: 48.9% A: 41.3% D: 8.7% SD: 1.1%
	The three dimensional structure of a molecule and its subcellular localization impact its function, including the ability to catalyze reactions or interact with other molecules.		The size, shape, and physical properties of organs and organisms all affect function. The ratio of surface area to volume is particularly critical for structures that function in transport or exchange of materials and heat.		Competition, mutualism, and other interactions are mediated by each species' morphological, physiological, and behavioral traits.	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
3.70 (0.04)	3.68 (0.04)	3.59 (0.04)	3.64 (0.04)	3.61 (0.04)	3.60 (0.04)	
SA: 72.8% A: 22.8% D: 3.8% SD: 0.5%	SA: 71.2% A: 26.6% D: 1.6% SD: 0.5%	SA: 65.2% A: 28.8% D: 6.0% SD: 0%	SA: 65.8% A: 32.1% D: 2.2% SD: 0%	SA: 65.2% A: 31.0% D: 3.8% SD: 0%	SA: 60.9% A: 38.0% D: 1.1% SD: 0%	
The structure of molecules or organisms may be similar due to common ancestry or selection for similar function.		Structure constrains function in physiology; specialization for one function limits a structure's ability to perform another function.				
Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy			
3.64 (0.05)	3.64 (0.04)	3.47 (0.05)	3.50 (0.05)			
SA: 70.1% A: 23.9% D: 5.4% SD: 0.5%	SA: 67.4% A: 29.9% D: 2.2% SD: 0.5%	SA: 56.0% A: 35.3% D: 8.2% SD: 0.5%	SA: 56.5% A: 37.0% D: 5.4% SD: 1.1%			
<b>Molecules (Smaller and faster)</b>			▶	<b>Ecosystems (Larger and slower)</b>		
<b>Biological Scale</b>						

Major Sub-disciplines of Biology						
Molecular/ Cellular/ Developmental Biology		Physiology		Ecology/ Evolutionary Biology		
<b>TRANSFORMATIONS OF ENERGY AND MATTER</b>	<b>Overarching Principles:</b> <i>Life takes work – it can only be sustained with inputs of energy.</i>  <i>Natural selection has favored the evolution of regulatory systems that allow individuals to use limited resources efficiently.</i>					
	Importance for graduating biology major			Scientific accuracy		
	3.70 (0.04)			3.43 (0.05)		
	SA: 73.4% A: 21.7% D: 4.3% SD: 0.5%			SA: 56.0% A: 33.1% D: 9.2% SD: 1.6%		
	<i>Energy captured by primary producers is stored as chemical energy and used to drive production of ATP via cellular respiration and other processes.</i>		<i>Energy captured by primary producers is stored as chemical energy. Organisms use chemical energy to drive the production of ATP. ATP is required for energetically demanding activities necessary for life, including movement, transport and synthesis.</i>		<i>Primary producers convert solar and other types of energy into chemical energy. At each trophic level, most of this energy is used for maintenance, with a relatively small fraction available for growth and reproduction. As a consequence, each trophic level in an ecosystem has less energy available than the preceding level.</i>	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
	3.80 (0.03)	3.66 (0.04)	3.77 (0.03)	3.67 (0.04)	3.65 (0.05)	3.58 (0.04)
	SA: 81% A: 17.9% D: 1.1% SD: 0%	SA: 66.9% A: 32.1% D: 1.1% SD: 0%	SA: 78.8% A: 19.6% D: 1.6% SD: 0%	SA: 70.7% A: 26.1% D: 3.3% SD: 0%	SA: 71.2% A: 22.8% D: 5.4% SD: 0.5%	SA: 62.5% A: 33.7% D: 3.3% SD: 0.5%
	<i>In cells, the synthesis and breakdown of molecules is highly regulated. Biochemical pathways usually involve multiple reactions, each catalyzed by an enzyme that lowers the activation energy. Energetically unfavorable reactions are driven by coupling to energetically favorable reactions such as ATP hydrolysis.</i>		Due to the inefficiency of biochemical reactions and other constraints, physiological processes are never 100% efficient.		Chemical elements are transferred among the abiotic and biotic components of an ecosystem; changes in the amount and distribution of chemical elements can impact the ecosystem.	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
3.70 (0.04)	3.69 (0.03)	3.60 (0.05)	3.62 (0.04)	3.64 (0.04)	3.69 (0.04)	
SA: 73.9% A: 21.7% D: 4.3% SD: 0%	SA: 69.6% A: 29.9% D: 0.5% SD: 0%	SA: 66.8% A: 26.1% D: 7.1% SD: 0%	SA: 66.3% A: 29.9% D: 3.3% SD: 0.5%	SA: 67.4% A: 29.3% D: 2.7% SD: 0.5%	SA: 70.6% A: 27.7% D: 1.6% SD: 0%	
<i>Molecules move within and between cells via 1) energy-demanding transport processes and 2) random motion. A molecules' movement is affected by its thermal energy, size, concentration gradient, and biochemical properties.</i>		Organisms have limited energetic and material resources which must be distributed across competing functional demands. These include movement of material across gradients, growth, maintenance, and reproduction, inevitably leading to trade-offs.				
Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy			
3.58 (0.05)	3.61 (0.04)	3.56 (0.05)	3.66 (0.04)			
SA: 65.2% A: 28.3% D: 6.0% SD: 0.5%	SA: 63.0% A: 34.8% D: 2.2% SD: 0%	SA: 65.8% A: 25.5% D: 8.2% SD: 0.5%	SA: 66.9% A: 32.6% D: 0.5% SD: 0%			
<b>Molecules (Smaller and faster)</b>			▶	<b>Ecosystems (Larger and slower)</b>		
<b>Biological Scale</b>						

Major Sub-disciplines of Biology						
Molecular/ Cellular/ Developmental Biology		Physiology		Ecology/ Evolutionary Biology		
<b>SYSTEMS</b>	<b>Overarching Principles:</b> <i>Biological molecules, cells, tissues, organs, and individuals do not exist in isolation— they interact in a highly regulated way.</i> <i>Organisms have evolved complex systems to integrate internal and external information and respond to their changing environments.</i>					
	Importance for graduating biology major			Scientific accuracy		
	3.77 (0.04)			3.60 (0.05)		
	SA: 80.4% A: 16.8% D: 1.6% SD: 1.1%			SA: 68.5% A: 25.0% D: 4.9% SD: 1.6%		
	Cells receive a complex array of chemical and physical signals that vary in time, location, and intensity over the lifespan of the organism; a cell's response depends on integration and coordination of these various signals.		Organ systems are not isolated, but interact with each other through chemical and physical signals at the level of cells, tissues, and organs.		The size and structure of populations are dynamic. A species' abundance and distribution is limited by available resources and by interactions between biotic and abiotic factors.	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
	3.50 (0.05)	3.65 (0.04)	3.72 (0.03)	3.75 (0.03)	3.73 (0.03)	3.71 (0.03)
	SA: 59.8% A: 31.5% D: 0.5% SD: 0%	SA: 66.3% A: 32.6% D: 1.1% SD: 0%	SA: 72.8% A: 26.6% D: 0.5% SD: 0%	SA: 75.5% A: 23.9% D: 0.5% SD: 0%	SA: 74.5% A: 24.4% D: 1.1% SD: 0%	SA: 72.3% A: 26.1% D: 1.6% SD: 0%
	During development, the signals a cell receives depend on its spatial orientation within the embryo and its intercellular interactions. As a consequence, cells adopt different cell fates depending on their local environment.		An individual's physiological traits affect its interactions with other organisms and with its physical environment.		Ecosystems are not isolated and static—they respond to change, both as a result of intrinsic changes to networks of species and as a result of extrinsic environmental drivers. Within an ecosystem, interactions among individuals form networks; changes in one node of a network can cause changes in other nodes—directly or indirectly.	
	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy
3.54 (0.05)	3.67 (0.04)	3.52 (0.04)	3.60 (0.04)	3.68 (0.04)	3.68 (0.04)	
SA: 60.3% A: 33.2% D: 6.5% SD: 0%	SA: 67.0% A: 31.5% D: 0.5% SD: 0%	SA: 58.2% A: 35.9% D: 6.0% SD: 0%	SA: 62.5% A: 34.8% D: 2.7% SD: 0%	SA: 70.6% A: 27.2% D: 2.2% SD: 0%	SA: 69.6% A: 29.3% D: 1.1% SD: 0%	
Alteration of a single gene or molecule in a signaling network may have complex impacts at the cell, tissue or whole-organism level.		In the face of environmental changes, organisms may maintain homeostasis through control mechanisms that often use negative feedback; others have adaptations that allow them to acclimate to environmental variation.		Biodiversity impacts many aspects of an ecosystem. In general, species-rich ecosystems function are more stable and productive than species-poor ecosystems.		
Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	Importance for graduating biology major	Scientific accuracy	
3.61 (0.04)	3.68 (0.03)	3.60 (0.05)	3.54 (0.04)	3.48 (0.05)	3.34 (0.05)	
SA: 65.2% A: 30.4% D: 4.4% SD: 0%	SA: 68.5% A: 31.5% D: 0% SD: 0%	SA: 67.9% A: 25% D: 6.5% SD: 0.5%	SA: 58.7% A: 37.5% D: 3.3% SD: 0.5%	SA: 56% A: 35.9% D: 8.1% SD: 0%	SA: 47.8% A: 39.7% D: 11.4% SD: 1.1%	
<b>Molecules (Smaller and faster)</b>			▶	<b>Ecosystems (Larger and slower)</b>		
<b>Biological Scale</b>						

**Supplemental Table 1. Additional Concepts for the BioCore Guide.** National validation respondent suggestions for additional important concepts for graduating biology majors to know that are not currently included in the BioCore Guide. If multiple reviewers suggested a concept, the number of reviewer is shown in parentheses. We have organized them into the categories of the core concepts of Vision and Change when possible.

Evolution	<p>Life has three domains of diversity: Bacteria, Archaea, and Eucarya; each of which has unique characteristics and differences and has descended from a common ancestor (5)</p> <p>Commonality of developmental mechanisms used by a wide variety of disparate organisms (3)</p> <p>Communication between individuals; behavior is an important adaptation (3)</p> <p>History of life and patterns of extinction (2)</p> <p>Common ancestry – understanding that all life is related (2)</p> <p>Evolution of sex and sex differences</p> <p>How Darwin formulated the theory of evolution</p> <p>Timing of evolution</p> <p>Differentiate acclimation and adaptation</p> <p>Evolution of molecules</p> <p>Understanding that many of the cell and molecular mechanisms/processes in humans originated in prokaryotes</p> <p>Role of species interactions in structuring communities and shaping evolutionary patterns</p> <p>Natural history of plants and animals where they live</p> <p>Macroevolution</p>
Information Flow	<p>Osmosis/equilibrium/diffusion (2)</p> <p>Different steps of gene regulation</p> <p>The importance of randomness in biological systems, interactions, mutations, etc.</p> <p>Feedback loops (including both positive and negative feedback)</p>

	<p>Biological plasticity (behavioral, developmental, and genetic)</p> <p>Genetic code is approximately universal</p>
Structure Function	<p>Immune system, including innate and adaptive (2)</p> <p>Other non-organelle cell structures (cell membranes, ribosomes, etc.) (2)</p> <p>Influence of structure and behavior of water on molecular/cellular functions</p> <p>Stem cells – what they are, how they are created, and their roles</p> <p>Organisms provide environment that houses other organisms and pathogens</p> <p>Biomes is a critical concept relating to the ecological level of structure</p> <p>Ecological structure changing over times relates to disturbance and succession</p> <p>Conformational change in macromolecules</p>
Transformations of Energy and Matter	<p>Definition of life – living cells that are taking in energy and giving off waste (2)</p> <p>Energy sources on Earth and spectral distribution of energy that reaches the Earth from the sun</p> <p>Light capture is mechanism by which energy is transformed</p> <p>Biogeochemical cycling and decomposition are important for understanding ecosystems</p> <p>Importance of Carbon and Oxygen for life</p>
Systems	<p>Metagenomics</p> <p>Community structure</p> <p>Emergent properties</p> <p>Life is so diverse because of myriad interactions among species</p>
Other	<p>Competencies (11)</p> <p>Parasitism</p> <p>Cancer</p> <p>Climate change</p> <p>Disease/infection</p>