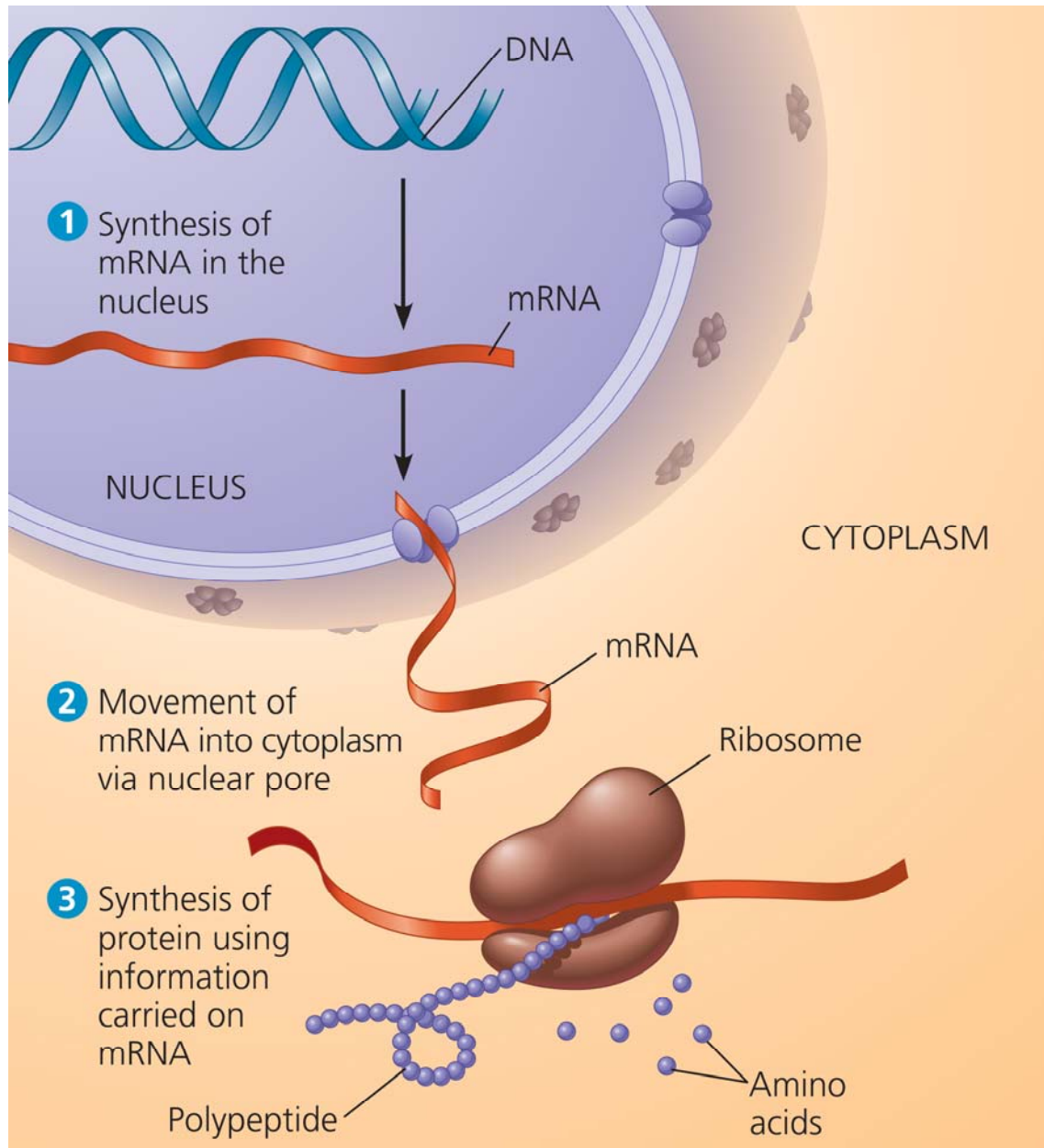
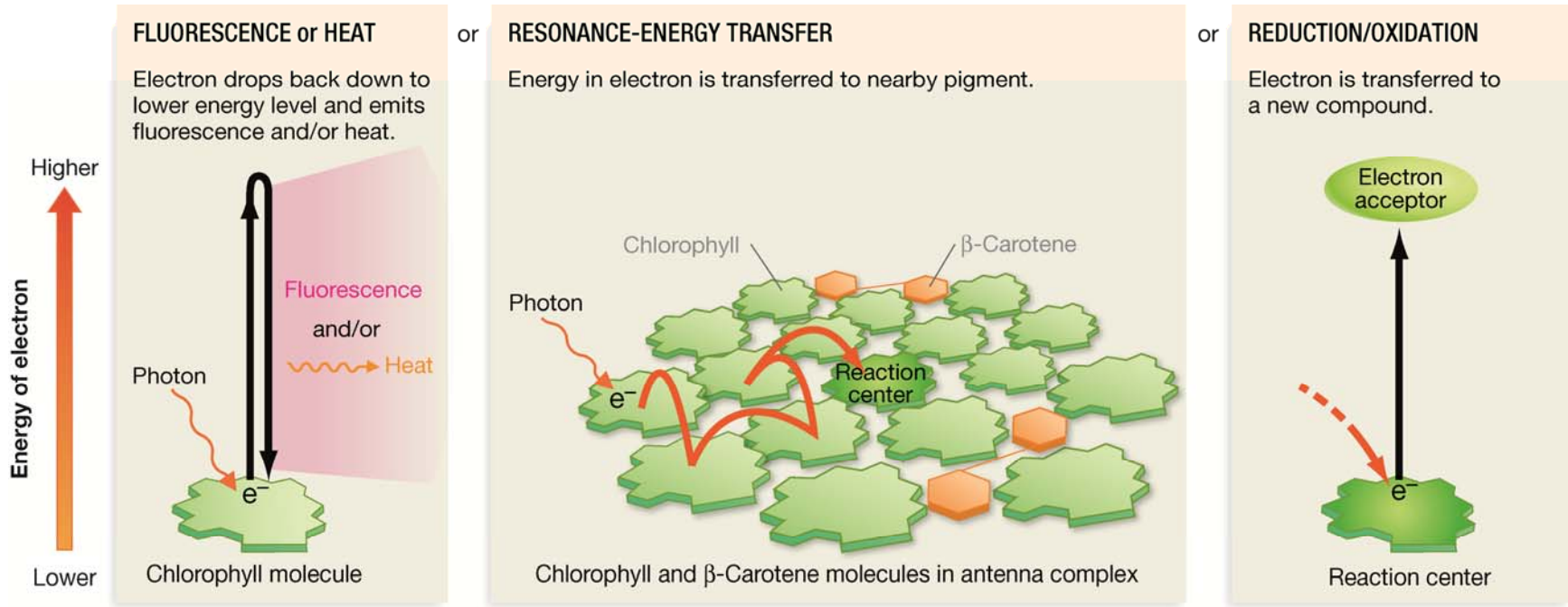


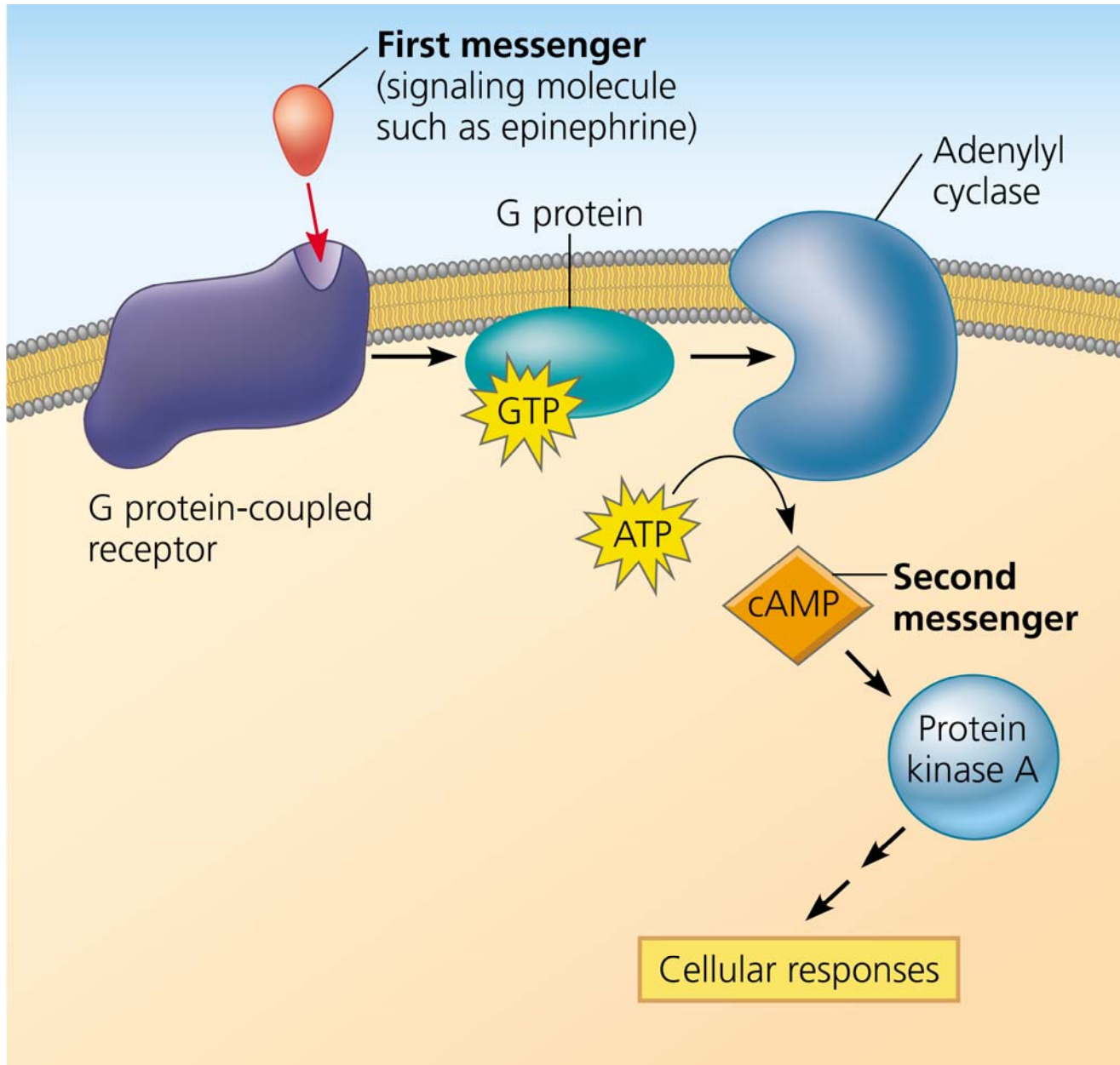
Supplemental Material

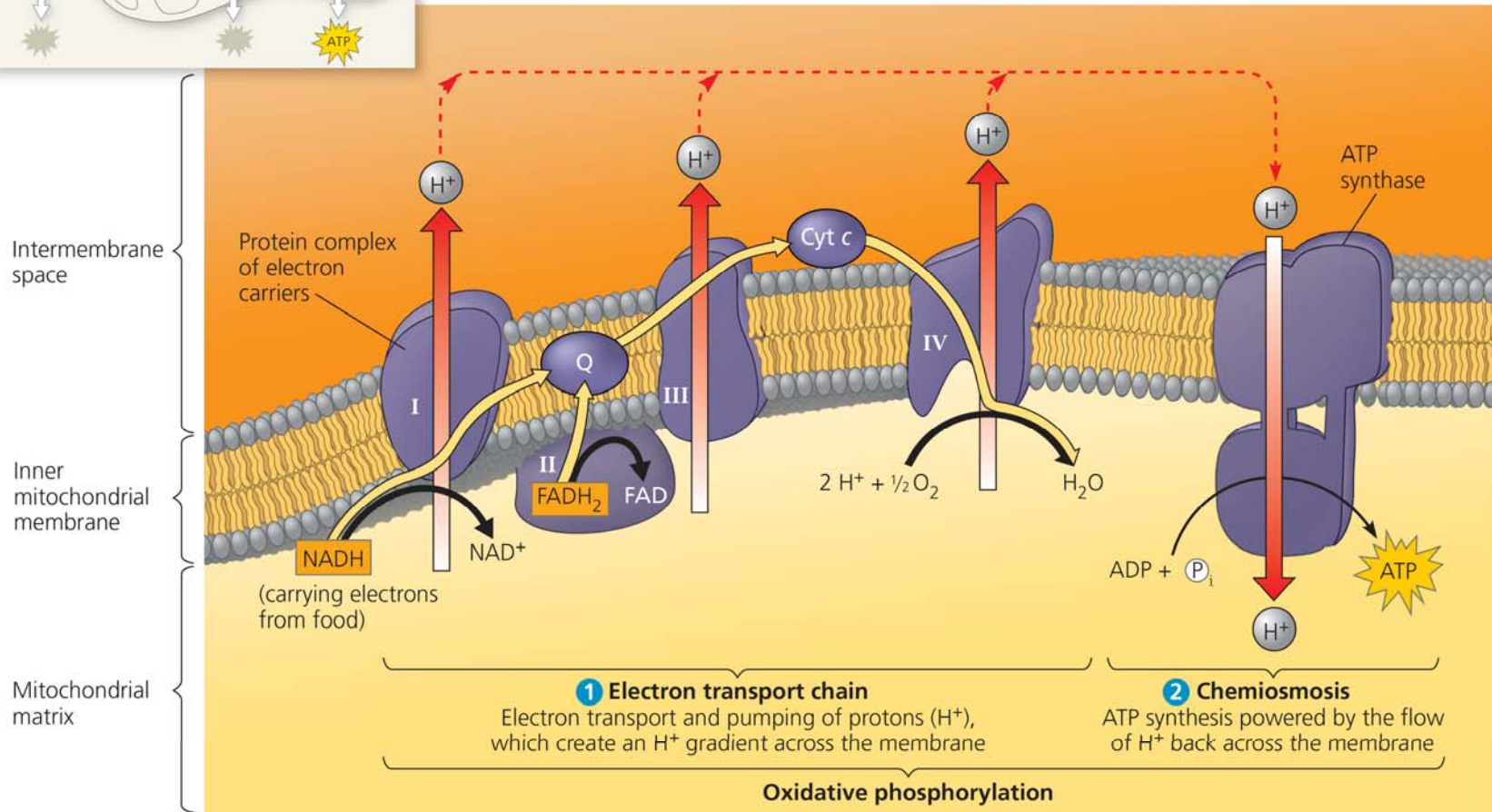
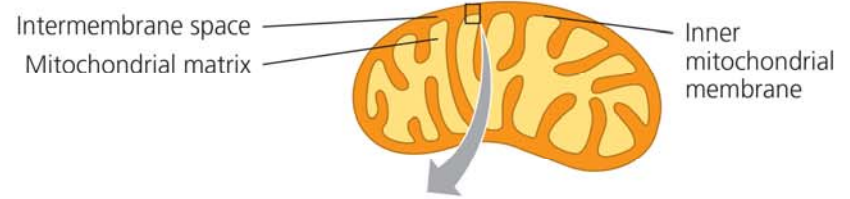
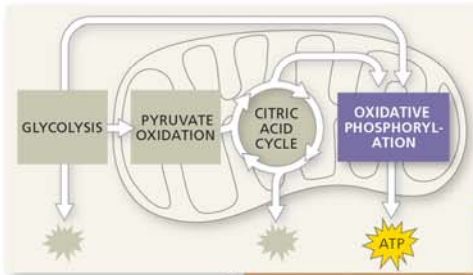
CBE—Life Sciences Education

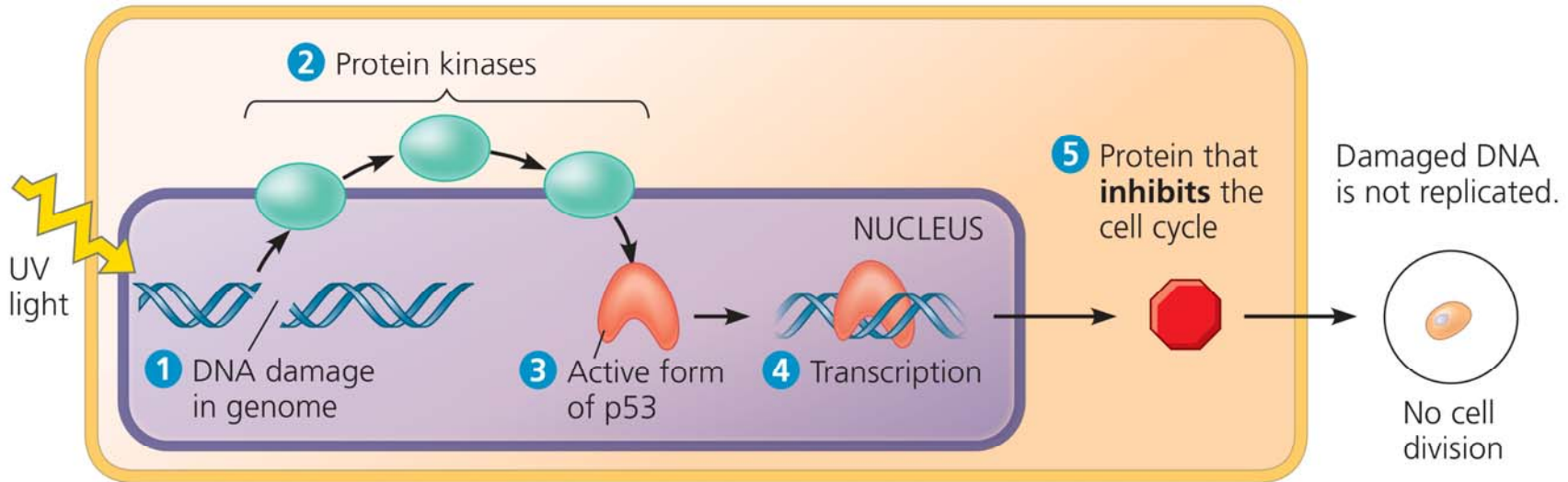
Wright *et al.*



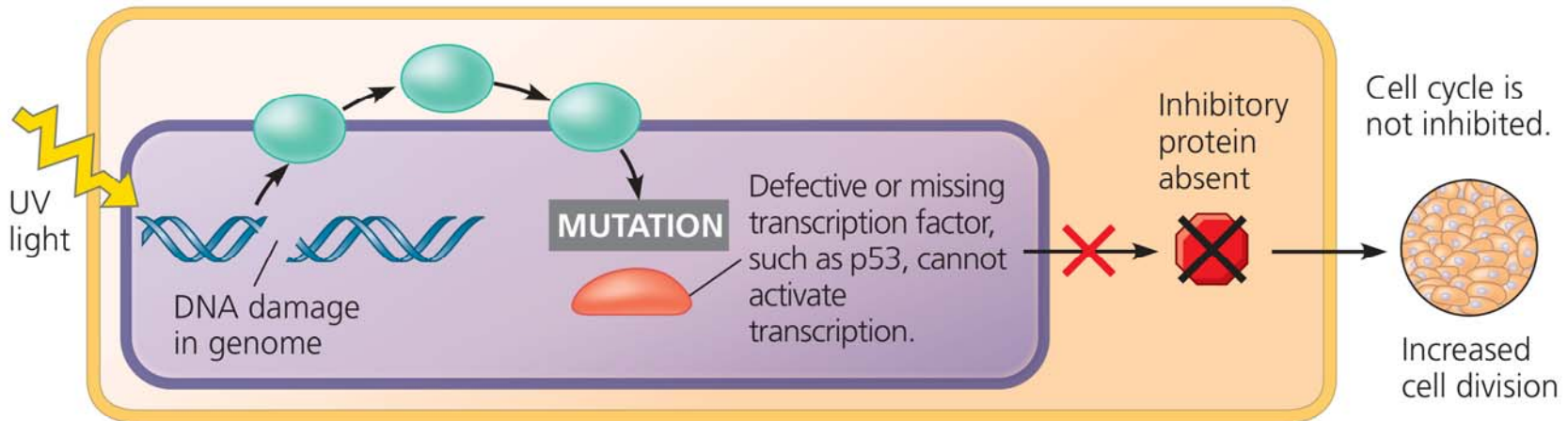




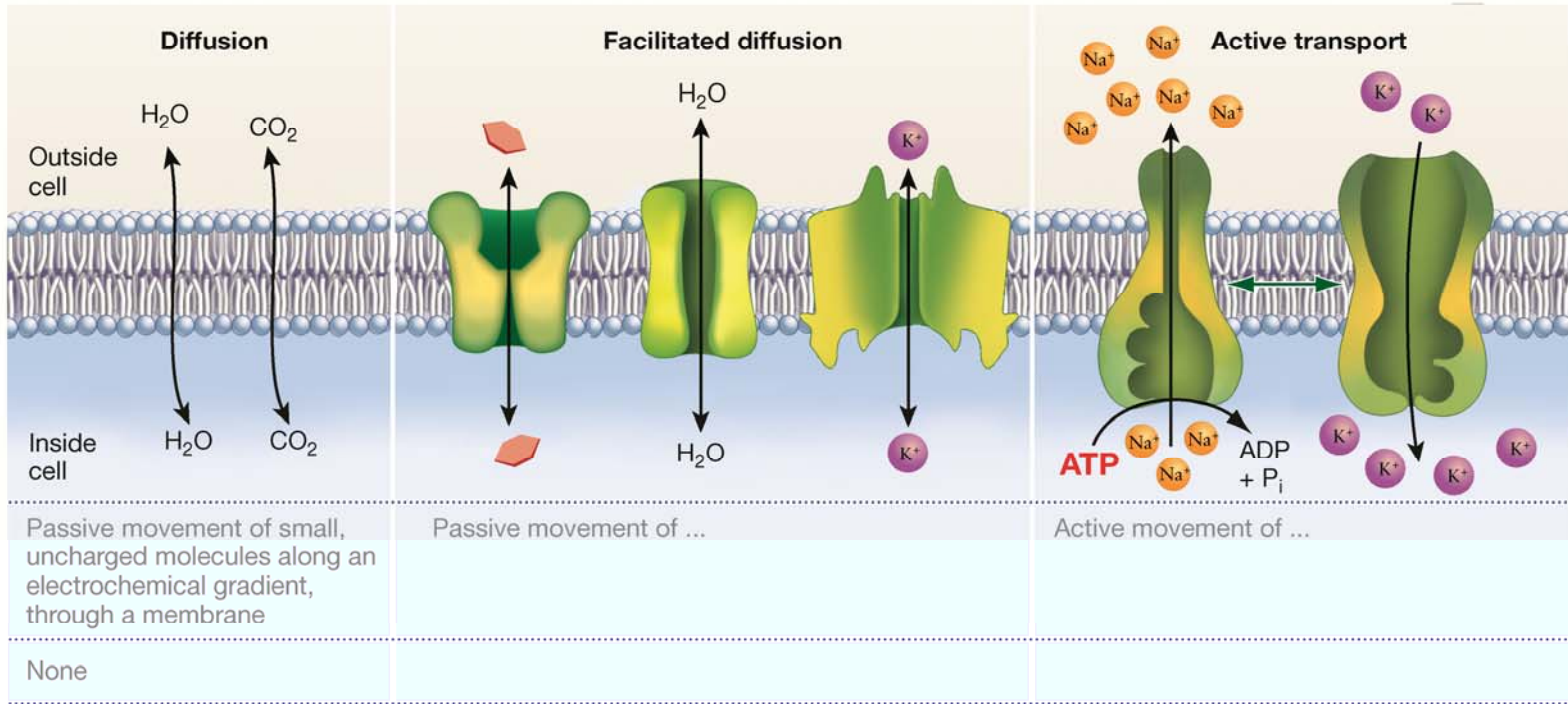


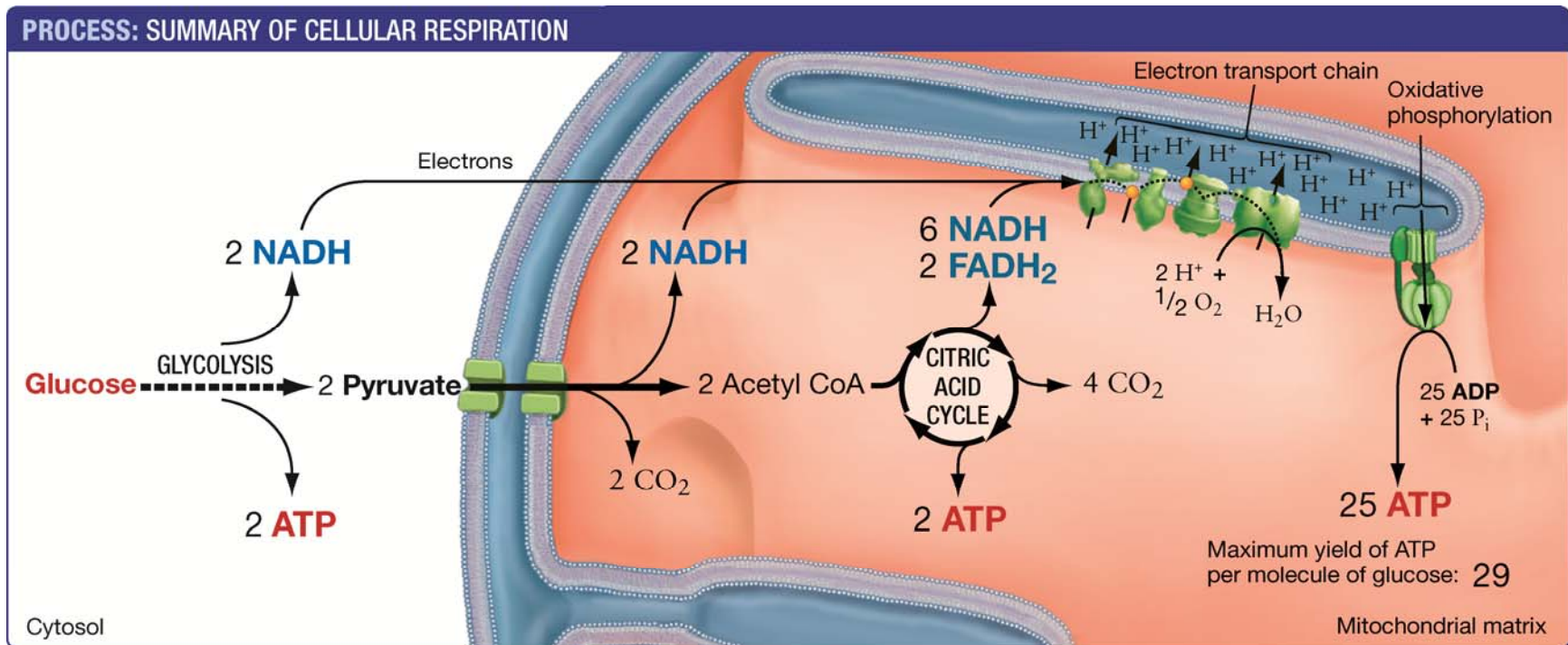


(a) Normal cell cycle-inhibiting pathway



(b) Mutant cell cycle-inhibiting pathway





Supplemental Figure 1. Textbook figures that were used during interviews with undergraduate students. All images are reprinted with permission from Pearson Higher Ed. Images A-D came from *Campbell Biology in Focus*, 2nd ed. (Urry et al., 2016). Images E-G came from *Biological Sciences*, 5th ed. (Freeman et al., 2014). **A)** Figure 3.26. Gene Expression: DNA → RNA → Protein. (Numbered steps were removed from the figure for interviews) **B)** Figure 5.25. cAMP as a second messenger in a G protein signalling pathway. **C)** Figure 7.14. Chemiosmosis couples the electron transport chain to ATP synthesis. (Numbered descriptions were removed, though their labels were kept. The corresponding numbers were removed from the figure legend as well). **D)** Figure 16.19. Normal and mutant cell-cycle inhibiting pathway (Panels a and b were used during interviews and the numbers signifying certain steps were removed). **E)** Figure 6.26. Summary of the Active and Passive Membrane Transport (only the third panel was used during interviews). **F)** Figure 9.19. ATP Yield during Cellular Respiration. **G)** Figure 10.10. Four Fates for Excited Electrons in Photosynthetic Pigments.

Supplemental Table 1. Arrow codebook, showing how 73 very specific codes were collapsed into 12 broad conceptual meaning categories.

New Category	Original Category	Meaning
change over time	Passage of Time	Indication of time passing
	Change in value	Indication that something has increased or decreased (e.g. body weight, tissue mass)
	Causation	Indication that some sort of cause and effect is taking place. (e.g. high glucose causes inactive adenylly cyclase)
	Evolutionary Progression	Indication of the next stage of evolution
	Secondary Endosymbiosis within a Phylogeny	The tail of the arrow indicates the engulfed and the point of the arrow indicates which ancestor was the engulfer for secondary endosymbiosis
change over distance	Gradient	Arrows that indicate some sort of gradient from either from high to low or vice versa
	Migration	Indication of the possible path that animals migrated from one location to another
flow of information	Allele Transmission	The arrow indicates passing/transmitting a particular allele
	Combination of Gametic Chromosomes (Fertilization)	Indication of two gametes that are depicted with chromosomes fusing to produce a fertilized egg that also show the chromosomes
	Results of a cross at phenotypic level	Two different organisms that have two different phenotypes mate and produce offspring with different phenotypes
	Generation Advancement	Indication of the advancement of a generation from parent to offspring
	Independent Assortment of Alleles in Gametes	The arrow represents one way a gamete can have different alleles (ex. RrYy -> RY, Ry, rY, ry)
	Crossing Over	Indication of crossing over or possibility of crossing over

	Gene Regulation/Interaction	The tail of the arrow indicates the gene that regulates and/or interacts with the point of the arrow
	Lateral Gene Transfer within a Phylogeny	The arrow indicates that lateral gene transfer occurred within a phylogenetic tree. The tail of the arrow indicates the species that transferred some of its genes to the species at the point of the arrow.
energy or matter transformation	Act of reacting	The substance at the tail of the arrow will react with the substance at the point of the arrow. Point of the arrow is not the product!
	Chemical Reaction	The traditional chemistry reaction arrow (reactants --> products)
	Mechanism of Chemical Reaction	indicates the parts of molecules that react, e.g. nucleophilic attack
	Production of a Product (reaction)	The reactant(s) is/are at the tail and the point is the product (macromolecules or words or pictures, not chemistry representation)
	Alternative Pathways	Indication of a substance that can be used/altered in different ways
	Multiple Steps in a Pathway	Indication that there are multiple steps occurring one after another in a pathway without showing the intermediates
	Side Product of a Pathway	A product that is produced and leaves the pathway, but is not the "main" product according to the figure.
	Step in a Pathway	The arrow indicates the next step in a pathway
	Step in a Process	Indication of the next step in a detailed process. Within the figure, the detailed intermediates are shown, so it is not just reactants and then the final product
	Phosphorylation	A substance that gains a phosphate group
	Dephosphorylation	A substance loses a phosphate group
		Dissociation of a Molecule

	Energy Flow/Transfer	Indicates energy moving/transferring from one entity to another
	Protein Shape Change	The arrow indicates that a protein will change its shape
movement	Movement of a Substance	Indication that a substance is moving in the direction of the arrow. Substance in this definition includes blood, water, macromolecules
	Movement of an Electron	The arrow indicates that electrons are moving from one place to another
	Movement of an Object	Indication of the direction that an object is moving. Object in this definition means that it is big enough to see with our naked eye
	Movement of Ions	Indication of the direction that ions are moving
	Diffusion Equilibrium	Indication of solutes in equilibrium through diffusion
	Rejection of Object/Substance	The arrow indicates that the object/substance is refused entry and "bounces off"
	Osmosis	Arrow indicates that water is moving from low solute concentration to high solute concentration or at equilibrium if water potentials are the same
	Gain Metabolic Water	Indication that metabolic water is gained in a system (e.g. H ₂ O produced as a result of metabolic pathways)
	indication of a quantity or point	Graph Axes
Measurement		The arrow indicates a numerical length associated with it. Can be explicitly stated, with a variable, or indirectly using the figure (ex. Y-axis has numbers and can estimate the number)
Zone		Indication of different zones/layers/range in a figure that does not indicate a numerical value.
	Continuum Scale	The arrow indicates a continuum between two different possibilities (ex. Low to high, small to large,

		temp)
	Angle	Indication of an angle in degrees
	Trendline on a Graph	Indication that there is a trend with the data
	Emphasis on a Point in a Gene	The arrow emphasizes what is important to look at on a gene
	Emphasis on a Point	The arrow emphasizes what is important to look at
	Specific Examples of the Topic	Indication that example(s) is/are given for the general topic
	Explanation	The tail of the arrow is explained at the point of the arrow
interaction/dissociation	Binding of a Substance	The substance is at the tail of the arrow and the point of the arrow indicates where the substance will bind
external action applied	Addition of a Reactant to an Experiment	The substance is at the tail of the arrow and the point of the arrow indicates where the substance will be added
	Force	Indication that an external force causes a change in the motion of the object such as pressure
	Step in a Protocol	Indicates the next step in a protocol
	Stimulus	Indicates a stimulus is added to a subject/object
	Sampling	Taking a sample from a pool
change in scale	Zooming	The arrow indicates that zooming in/out has occurred
directionality within an object	Body Axes	Arrows are used to indicate the directionality and symmetry of the body/object
	Polarity of Macromolecules	The arrow indicates 5' to 3', N to C, etc.
	Beta Pleated Sheets	Arrows that are used to represent beta pleated sheets and their directionality
progression through a system	Directionality	Something acts on/within a system with a particular directionality (e.g. evaporation moves toward the air)
	Signaling	The arrow indicates the flow/direction of the signal

	Process	The arrow is a generalized representation that a process has occurred. Process is defined as unable to stop in the middle and get a product/intermediate according to the figure at hand. Pathway is defined as being able to stop at steps and have a product/intermediate in the figure at hand.
	Electron Transport Chain	A generalized representation of the electron transport chain
	Feedback Control	When a product is used to control the production of the product. When a substance is used to control/regulate a process.
	Cycle	A generalized representation of a cycle (no intermediates/chemistry shown)
	Step in a Cycle	The arrow indicates the next step in a cycle
	Multiple Steps in One	The arrow represents many steps/processes/pathways taking place to reach a final product. Basically it skips a lot of the "middle" part to get to the final product. This is different from "process" because "process" deals with one process such as one arrow to denote "glycolysis".
input/output	Entry into a Cycle	Indication that a substance is entering into a cycle from the outside
	Products of a General Cycle	Products that are coming from a generalized representation of a cycle
	Step in a Cycle with a Side Product	Indication of a side product being produced and leaving the cycle in one of the steps
	Heat Energy	The energy being produced is heat
	Light energy Added	The source of energy is in the form of light
	Other Energies Released	The energy that is being produced/used that is NOT light or heat (ex. Kinetic, mechanical energies, fluorescence)

	Entry into a Process	Indication that a substance is entering into a process from the outside
	Side Product of a Process	A product that is produced and leaves the process, but is not the "main" product according to the figure. Process is defined as unable to stop in the middle and get a product/intermediate according to the figure at hand. Pathway is defined as being able to stop at steps and have a product/intermediate in the figure at hand