Cell Biology Questions and Learning Objectives

(with hypothetical learning materials that might populate the objective)

The topics and central questions listed here are typical for an introductory undergraduate cell biology course. Learning outcomes are what we might expect students to be able to do once they have mastered these questions, and sample learning materials are meant to provide suggestions to instructors as to what activities students could take part in as a way to reach the learning outcomes related to a central question. The learning materials put emphasis on learner-centered instruction, with students analyzing data, designing experiments, evaluating arguments, or manipulating tangible representations of parts of a biological process, for instance. The material provided here is not meant to be all-inclusive, nor does it suggest that any particular cell biology course must meet all the learning objectives.

Membrane structure/function:

- How do varied membrane composition and the structural features of component macromolecules in different cells contribute to membrane function?

  Learning Objectives:
  - Draw the structure of a lipid and explain how the structure allows a lipid bilayer to spontaneously assemble in an aqueous environment
  - Explain the importance of membrane lipid and protein component structural asymmetries in membrane function.
  - Describe the process by which membranes grow, are turned over, or are absorbed

    Sample Learning materials:
    - Data and clicker questions demonstrating importance of lipid recycling to the overall homeostasis of the cell.
  - Explain why different membranes have different lipid and protein constituents

    Sample Learning materials:
    - Data analysis using lipid modifications in cell identity.
    - Experiment that demonstrates clustering of a particular membrane component
    - Prediction of how variation in the lipid composition of a membrane will affect the mobility of lipids and integral membrane proteins.
    - An activity to design an experiment that demonstrates membrane fluidity changes in response to the environment.

Membrane transport:

- How do solutes and other materials move across membranes?

  Learning Objectives:

- Given a set of molecules of differing solubility in water, predict their relative rates of diffusion across a membrane bilayer.
- Compare and contrast the properties and functions of channels and carriers.

  Sample Learning materials:
  - Data analysis of movement of different solutes across membranes to determine mode of transport.
- Given data about the relative concentrations of solutes on both sides of a membrane, predict the direction of solute flow.
- Design an experiment that distinguishes between different modes of crossing the membrane, such as diffusion, facilitated diffusion, active transport

  Sample Learning materials:
  - Data analysis in which the rate of transport is measured at different solute and channel concentrations to predict if the transport process is mediated by diffusion or facilitated diffusion

Targeting and trafficking:

- How are cellular components targeted and distributed to different regions and compartments of a cell?

  Learning Objectives:
  - Discuss the differences in structure of a protein occupying its target destination in the cell and immediately after translation from the mRNA
  - Explain the mechanism and function of the unfolded protein response and its value to the cell.
  - Compare the general mechanisms that allow some newly synthesized proteins to be released into the cytoplasm, whereas others are directed into other cellular compartments

    Sample Learning materials:
    - Activity to analyze how the orientations of transmembrane proteins are determined as they are integrated into a membrane.
  - Identify the different cellular compartments in a eukaryotic cell and their main functions in the cell
  - Analyze data to determine the path taken by a protein that normally resides in an organelle/compartment or is secreted from the cell from its site of synthesis to its final destination

    Sample Learning materials:
    - Data analysis of pulse/chase experiment involving proteins that move through the secretory pathway.

        - Clicker question-based examination of the mechanism by which mutations in a motor protein change particle /organelle /localized protein movement/localization within the cell
        - Demonstration of chaperones assisting in the folding of newly translated proteins or in the formation of protein complexes.
    - Given data on effects of drugs and other functional manipulations on entry of various molecules and particles into the cell, determine what pathway is used for entry.

      Sample Learning materials:
        - Analysis of an experiment that distinguishes the mechanism by which different viruses enter cells
        - Use florescent markers for various compartments and structures and inhibitors that affect transport to determine the compartment /region of enrichment of particular proteins and/or the mechanism by which they are localized.
    - Compare the molecular recognition events and mechanisms required for movement of proteins through different uptake and secretion pathways

Nuclear structure/function:

- How does the structure of the nucleus affect chromosome organization and gene expression?

Learning Objectives:

- Describe the arrangement of chromosomal DNA in the nucleus and how it changes during the cell cycle.

  Sample Learning materials:
    - Data demonstrating changes in chromosomal organization that affect gene expression.
- Compare and contrast how the presence of a nucleus in eukaryotes and its absence in prokaryotes alters the dynamics of gene expression.

  Sample Learning materials:
    - Mechanisms by which the nuclear envelope in eukaryotes facilitates alternative splicing demonstrated using a video animation
    - Examples of situations where regulation of protein localization influences gene expression.
- Design an experiment to demonstrate the role of the nuclear pore complex.

  Sample Learning materials:

        - The mechanism used to regulate whether a protein is located in, or excluded from, the nucleus illustrated using clicker-based discussion.
    - From an evolutionary perspective, propose a mechanism that gave rise to the eukaryotic nucleus.

      Sample Learning materials:
        - Using the statement: “Eukaryotes are derived from a hybrid between an archael and a bacterial cell,” students provide evidence in support.
        - Homework assignments in which students propose a plausible alternative scenario to the statement, “Eukaryotes are derived from a hybrid between an archael and a bacterial cell.”
    - Diagram where ribosomal components are synthesized and where they are assembled.

Cytoskeleton:

- How do the different components of the cytoskeleton support a variety of cell functions, such as cell shape, division, movement, sensing the environment, and cell-cell communication?

  Learning Objectives:
    - Compare the characteristics and functions of microfilaments, microtubules, and intermediate filaments.

      Sample Learning materials:
        - Exercise that uses diagrams that show the process of cell division to explain the roles of different cytoskeletal polymers in the process.
        - A set of data showing defects in the cell division process (chart, diagram, micrograph), to evaluate what cytoskeletal-associated process has failed (microtubule, checkpoint proteins, motors, etc.)
        - Information that shows different effects of cytoskeletal inhibitors on different cell types to distinguish specialized roles of cytoskeletal structures.
    - Compare the structure and dynamic properties of microtubules versus actin and how these properties contribute to the different functions of these polymers in cells

      Sample Learning materials:
        - Experiment that demonstrates the role of polymer dynamics in cell shape, organization, division, structural integrity, or movement.

        - Effects of cytoskeletal-associated protein on cytoskeleton dynamics used to predict their functions in vivo
        - Microtubule dynamic instability comparison between interphase and mitosis.
    - Explain how motor proteins harness energy to move along cytoskeletal tracks

      Sample Learning materials:
        - Data analysis using truncated/domain-deleted motor proteins to examine the roles of the motor (head) and tail domains

Cell cycle/cell division (mitosis and meiosis):

- How do cells conduct, coordinate, and regulate nuclear and cell division?

  Learning Objectives:
    - Predict how a mutation or other functional alteration in a cytoskeletal protein will affect the progress of nuclear and cytoplasmic division.
    - Defend the argument that the presence of a cell wall in plants and fungi requires a different method for dividing the cytoplasm than that used in animals.
    - Evaluate the relative contribution of mutations in tumor suppressor genes and proto-oncogenes in the development of cancer
    - Assess the usefulness and limitations of information obtained from several experimental techniques (i.e., TEM, atomic force microscopy, fluorescent antibody labeling, and confocal fluorescence time lapse microscopy) in dissecting cytoskeletal roles in nuclear and cell division.
    - Compare different methods used to coordinate cell division in different cell types.

      Sample Learning materials:
        - Discussion activity to introduce what a cell measures at different cell cycle checkpoints and the mechanism of the measurement.
        - Phenotypic information about a novel cell cycle mutant used to explain the mechanism of its effect/component likely to be affected.
    - Compare and contrast organization of the mitotic spindle in animal, fungal, and plant cells and discuss the evolutionary and functional relevance.

Cell communication:

- How do cells send, receive, and respond to signals from their environment, including other cells?

Learning Objectives:

- Explain how a cell's interactions with its environment can influence cell morphology, behavior, division, or survival.

  Sample Learning materials:

  - Data that illustrated the ways in which interactions with the extracellular matrix, another cell, a signaling molecule, a pathogen, or symbiont can influence cell function through signaling.
  - Demonstration that contrasts how a cell poison and an external cell signal influences cell function.

- Compare and contrast the molecular mechanisms of membrane receptor-mediated and nuclear receptor-mediated signal transduction.
- Describe different mechanisms by which a membrane-bound receptor can affect cell physiology or behavior.

  Sample Learning materials:

  - A demonstration of how external signals can be amplified within a cell.
  - Information about the effect of one signal on several different cells to demonstrate how cells respond to the same external signal differently.
  - Examples that demonstrate the mechanism and role of signaling events that leads to irreversible change in cell behavior.
  - Data analysis that evaluates whether a given cell change/ phenomenon is more likely to be due to changes in gene expression or protein activity/signal transduction.
  - An exercise to design an experiment that determines if a change in cell behavior requires changes in gene expression.
- Choose an everyday human experience and explain how it is mediated by cellular changes due to an external signal.
- Describe how the presence of gap junctions alters cellular responses to extracellular signals.

Matter and Energy transformation:

- How do cells transform energy and cycle matter?

Learning objectives:

- list the types of energy used by cells and give examples of when / in what cells / situations the different energy sources are used
- explain why energy transformations are necessary in the cell

  Sample Learning materials:
  - Discussion questions on mechanisms by which cells drive thermodynamically unfavorable reactions
- Diagram the energy transformations used in glycolysis, respiration and photosynthesis in a plant cell

  Sample Learning materials:
  - Diagrams of the flow of electrons in glycolysis, respiration, and photosynthesis
  - Exercise that traces the movement of carbon atoms in glycolysis, respiration and photosynthesis
- Explain how cyanide, an electron transport chain inhibitor, impacts oxygen consumption within animal cells

Cell Specialization:

- How can and why do cells with the same genomes have different structures and functions?

Learning Objectives

- Describe the role of differential gene regulation causes cell differentiation.
- Compare and contrast the structure and function of different cell types.
- Predict how a drug with a known target would affect the function of a specific cell type (e.g., a neuron).

Sample Learning materials:
  - Data on the effects of a drug on action potentials in a nerve cell used to predict if the drug is affecting sodium or potassium channels.
- Evaluate the strength and limitations of pieces of evidence in support of the claim that a particular inherited diseases affects a specific cell type.
- Evaluate the benefits of cell specialization in organisms with varying degrees of complexity.
- Evaluate evidence in support of the claim stem cells have great potential in the treatment of a variety of human diseases.

Multicellularity/cell connections:

- How do cells connect to each other and organize to function as a collective entity?

  Learning Objectives:

  - Differentiate the ways plant, animal and fungal cells are connected to each other and exchange materials independent of membrane transport.

    Sample Learning materials

    - Comparisons of the extracellular matrices and their functions in eubacteria, archae, plants, fungi and animals.
    - Properties of intercellular connections and extracellular structures in animals and plants and how they constrain cell movement
  - Evaluate the claim that colonial organisms are multicellular.
  - Compare and contrast cell communication in unicellular and multicellular organisms in response to pathogens, symbionts, and physical and chemical signals.
  - Evaluate the importance of cell-cell communication in coordinating function in multicellular organisms.
  - Given an example of apoptosis, analyze its potential effect on fitness of the organism.

Evolutionary history of cells:

- How does evolutionary history explain the similarities and differences among cells?

  Learning Objectives:

  - Evaluate data about the evolutionary relatedness among eukaryotes, archae, and bacteria, including caveats or limitations
  - Evaluate the case for cytoskeleton evolution from bacterial components.
  - Describe the major types of genomic changes that are important in cellular and organism evolution

    Sample Learning materials

    - Description of gene duplication that explains its role in evolution of cell function.
  - Compare and contrast cellular structure and function in eubacteria, archae and eukaryotes in the context of their evolutionary history.

    Sample Learning materials

        - Data on organelle structure used to determine whether the organism evolved through primary, secondary, or tertiary endosymbiosis.
        - Exercise to assemble and evaluate the evidence for the proposed origins of a eukaryotic organelle.
        - Homework assignment to identify cell properties that were most dramatically altered by natural selection during evolution of multicellularity.
    - Construct an explanation for the interrelatedness of photosynthesis and respiration in an evolutionary context.

Methods and Tools:

- How do the methods and tools of cell biology enable and limit our understanding of the cell?

Learning Objectives

- Assess the usefulness and limitations of information obtained different types of microscopy.

  Sample Learning materials

  - Data from several microscopic techniques (e.g., fluorescent antibody labeling and confocal fluorescence time lapse microscopy) used to dissect cytoskeletal roles in nuclear and cell division.
  - Fluorescent protein (GFP, etc) fusion to a protein of interest used in prediction of the protein's localization at different phases of the cell cycle.
  - Different ways to fluorescently tag cellular proteins.
  - Comparison of transmission electron microscopy (TEM) and scanning electron microscopy (SEM) use to evaluate cell organization in a tissue.
- Describe different strategies to break open cells and isolate cellular organelles.
- Give an example of how the study of temperature-sensitive mutants was instrumental in elucidating the details of a cellular pathway.