



ASPB – BSA Core Concepts and Learning Objectives in Plant Biology for Undergraduates



The American Association for the Advancement of Science, National Science Foundation (NSF), and other stakeholders recently published a call to transform undergraduate biology education, titled *Vision and Change* (<http://visionandchange.org/finalreport>). Major themes of *Vision and Change* include teaching core concepts and competencies, focusing on student-centered learning, promoting campus-wide commitments to change, and engaging the biology community in implementation of change. The American Society of Plant Biologists (ASPB) and Botanical Society of America (BSA) were among the first societies to become involved in *Vision and Change*. NSF awarded ASPB a grant to host a workshop in 2011 to gather feedback from plant biologists on how to put the *Vision and Change* recommendations into practice. One of the major concerns that emerged from this workshop was the lack of a defined set of core concepts in plant biology that undergraduates should learn. This lack results in underrepresentation or misrepresentation of plants in undergraduate curricula and misunderstanding about the importance and unique functions of plants and their broader contributions to understanding biology (e.g., plants “don’t do much;” plants are “only important for photosynthesis;” plants are “not interesting” to study).

To address these concerns, a working group of ASPB and BSA members was assembled: Kathleen Archer (Trinity College), Erin Dolan (University of Georgia), Roger Hangarter (Indiana University), Ken Keegstra (Michigan State University), Judith Skog (George Mason University), Susan Singer (Carleton College), Neelima Sinha (UC Davis), Anne Sylvester (University of Wyoming), and Sue Wick (University of Minnesota). The working group was tasked with generating a set of core concepts that:

- outline what undergraduate biology majors should learn about plants;
- are consistent with themes from *Vision and Change* and the new K-12 science education framework;
- are the enduring, big ideas that explain what makes plants distinct from other lineages of organisms and describe the essential attributes and life strategies of plants; and
- are broad and foundational in nature, and can be divided further into multiple sub-concepts or units of knowledge (e.g., learning objectives) that are measurable.

For the purposes of this effort, plants were defined as: *eukaryotic photosynthetic organisms with multicellular haploid and diploid stages in their life cycle and protected diploid embryos*.

ASPB and BSA members were invited to comment on a draft of the core concepts, and their feedback was used to generate the final version that follows. The concepts are organized into the four life science domains of the new framework for K-12 science education developed by the National Academy of Sciences Board on Science Education (http://www.nap.edu/catalog.php?record_id=13165): (1) *From Molecules to Organisms: Structures and Processes*, (2) *Ecosystems: Interactions, Energy, and Dynamics*, (3) *Heredity: Inheritance and Variation of Traits*, and (4) *Biological Evolution: Unity and Diversity*. Each set of concepts begins with a description of the foundational knowledge in the domain. Individual concepts are followed by sample learning objectives: what students could do to demonstrate their understanding of the concept. ASPB and BSA leadership urge all who teach undergraduate biology students to use this document as a guide for curricular design and instruction.

1. From Molecules to Organisms: Structures and Processes. Plants are living organisms that grow, reproduce, and die. Plants and their parts are made up of cells, which contain DNA and other molecules that support plant functions. Plants are attached and do not move from place to place to acquire resources for survival. Plants grow toward resources and have specific structures, called chloroplasts, which carry out the reactions of photosynthesis. Using the energy captured from sunlight, plants produce molecules to support their own growth and development. Plants also take up water and inorganic nutrients from their terrestrial or aquatic environment. Plant cells are bounded by cell walls that are essential for growth and development of the plant body.

1A: Structure and Function. *How do structures of plants enable life functions?*

- Plants growing in various environments have a diversity of structures for acquiring and retaining water, exchanging gases, optimizing photosynthesis, and supporting growth and reproduction.

Learning objective (LO): Compare and contrast the structures by which vascular and non-vascular plants obtain and retain water, allow for gas exchange for photosynthesis, and allow for long-distance internal transport of water.

LO: Map onto a phylogenetic tree of plants the locations where innovations for acquiring water, retaining water, exchanging gases, upright stature, and reproduction in the absence of swimming sperm arose.

LO: Analyze structural and anatomical features that optimize photosynthesis under various environmental conditions such as shading, water deficit, or high temperature.

- Plants have carbohydrate-based cell walls that serve diverse functions.

LO: Contrast the primary cell wall component of plants, fungi, and bacteria.

LO: Analyze the roles of cellulose and cell wall matrix components in support, growth, and cell-cell recognition as well as protection against pathogens.

- Plants have specialized structures and systems for defense against disease and predation.

LO: Categorize defense mechanisms into structural, constitutive biochemical, and induced biochemical responses, evaluating the cost and benefits of each.

- Plants have conducting tissues that transport water, carbohydrates, and nutrients through both passive and active mechanisms.

LO: Compare and contrast the long distance transport of carbohydrates with that of water and nutrients in a plant.

LO: Diagram the pathway of carbohydrate transport from a source to a sink, indicating where active transport is required.

- Some plants and plant parts are able to move.

LO: Categorize plant structures and their particular features that facilitate dispersal of the plant in the environment

LO: Select a plant structure that is capable of movement and analyze the features that enable it to move.

1B: Growth and Development of Organisms. *How do plants grow and develop?*

- Plants can reproduce sexually and asexually.

LO: Categorize examples of asexual reproduction based on the plant structures involved.

LO: Select a plant and diagram the contributions of the gametophyte(s) to sexual reproduction.

- Plants grow from single cells and retain groups of undifferentiated and dividing cells throughout their lives.

LO: Support the claim that plants continue to develop and differentiate new structures after formation of a multicellular structure by drawing and identifying regions of a plant with persistent meristem activity.

LO: Using examples, explain how shoots and roots are repeatedly added to a plant through meristem activity.

- Plant germ-line cells are established after vegetative growth has started.

LO: Explain when and where in the plant meiosis occurs.

- The development of plant form is influenced by external and internal cues.

LO: Categorize internal and external cues based on their effects on plant form.

LO: Draw a diagram that represents the effect of a specific wavelength of light on plant form; include photoreceptors, signal transduction, gene expression, and morphological change in the diagram.

LO: Draw a diagram that illustrates the effect of gravity on plant form; include receptors, signal transduction, gene expression, and morphological change in the diagram.

- Plants produce and respond to hormones that regulate growth and development.

LO: Identify the categories of plant hormones and provide examples of their effects on growth and development.

LO: Compare and contrast the production of and response to a steroid hormone in a plant and an animal.

- Cell expansion depends on biochemical and biophysical processes, including wall loosening and water pressure inside the cell.

LO: Diagram how internal and external cues integrate to contribute to mechanisms of cell expansion.

1C: Organization of Matter and Energy Flow in Organisms. *How do plants obtain and use matter and energy to live and grow?*

- Plants capture light energy to assimilate inorganic carbon dioxide into organic compounds.

LO: Create a diagram showing how inorganic carbon is assimilated into organic compounds in plants and overlay this with the flow of energy through the plant.

- Plants take up and transport inorganic materials from their surroundings.

LO: Trace the path of movement of inorganic nutrients from soil into the aboveground part of the plant

LO: Compare the roles of mycorrhizae and root nodules in the uptake of inorganic materials in plants.

LO: Identify the two inorganic molecules that are used to produce the majority of a plant's mass, and indicate their sources.

LO: Explain how the availability of soil microorganisms has supported or limited the growth of economically important plants.

- Plants capture and use energy from sunlight. Almost all other organisms on the planet eat plants as a source of energy.

LO: For a terrestrial ecosystem, analyze the flow of energy among organisms.

- Plants photosynthesize and respire.

LO: Explain why plants can grow in a closed terrarium.

- Plants synthesize a wide variety of organic compounds through diverse biochemical pathways.

LO: Choose a class of organic compounds other than sugars and, in general terms, explain the carbon and energy sources for synthesis of these materials.

1D: Information Processing. *How do plants detect, process, and interpret information from the environment?*

- Plants detect and respond to physical and biological cues in their environment, including light, water, gravity, biochemical, and mechanical stimuli.

LO: Construct a representation of a molecular receptor for a physical or biological signal that clearly shows how the signal is detected and how information is conveyed from the receptor to the plant cell.

- Signals transmitted through a plant can induce changes in gene expression, protein activity, and protein turnover.

LO: Compare and contrast a signaling pathway that leads to the activation of a cytosolic enzyme and a pathway leading to changes in gene expression.

- Plants can respond to stimuli over a broad range of time scales.

LO: Choose a stimulus that has an immediate response in a plant and a stimulus that results in a response days or weeks later; compare and contrast the information processing in the two examples.

- Plants perceive and respond to each other and to other organisms in their environment.

LO: Diagram how a signal from a plant is perceived and acted upon by another plant.

LO: Compare and contrast how a plant detects, processes, and interprets information from an herbivore and a pathogen.

LO: Provide examples of how herbivory alters plant growth.

2. Ecosystems: Interactions, Energy, and Dynamics. Ecosystems are communities of organisms and their nonliving physical environment. Ecosystems are defined by complex hierarchical networks of interactions among individuals and populations, as well as interactions between organisms and their environment. All organisms in an ecosystem are linked through energy flow and cycles of water, carbon, nitrogen, and soil minerals. Energy enters the ecosystem mostly through photosynthesis and biomass production by plants. Other organisms obtain matter and energy from the plants. Decomposers act on dead organic matter, releasing carbon back to the atmosphere and facilitating nutrient cycling by converting nutrients stored in dead biomass back to forms that can be reused. Ecosystems are dynamic and changes in biotic and abiotic factors affect their stability and resilience. Humans are part of the biotic community and are having rapid effects on the biotic and abiotic aspects of ecosystems. In many cases, humans are placing profound stresses on the Earth's overall ecosystem to a point that ecosystem resilience, sustainability, and services are a major focus of concern.

2A: Interdependent Relationships in Ecosystems. *How do plants interact with the living and non-living environment?*

- Plants are the primary food and oxygen producers on Earth.

LO: Compare the relative contributions of plants and another photosynthetic organisms like lichens or terrestrial algae to production of food and oxygen on land.

- Plants are foundational to large ecosystems.

LO: Evaluate the statement that plants are the foundation of terrestrial ecosystems.

- Plants live in close association and interact with other organisms, including other plants, animals, fungi, and microorganisms.

LO: Choose an example of an interaction between a plant and another organism and elaborate on the ways in which they interact to the benefit of one or both organisms.

- Plants produce metabolites that affect other organisms in ecosystems.

LO: Choose a plant metabolite that affects other organisms in the ecosystem and explain the mechanism of the effect.

- Plants have changed and continue to change Earth systems.

LO: Evaluate the geological evidence that plants contributed to glaciation (i.e., ice ages).

LO: Contrast the general properties of plants, soil, and fauna on Earth at the time that plants first colonized dry land with the general properties of those organisms today.

LO: Analyze the progression of changes in plants and other organisms that occur after a volcanic eruption or a major wildfire.

2B: Cycles of Matter and Energy Transfer in Ecosystems. *How do matter and energy move through an ecosystem?*

- Energy first enters ecosystems through photosynthesis.

LO: Evaluate the claim that energy first enters the ecosystem through photosynthesis; consider relative to chemosynthesis.

- Plants cycle oxygen and carbon dioxide through photosynthesis and respiration.

LO: Create a diagram that illustrates the flow of oxygen and carbon dioxide through photosynthesis and respiration in an ecosystem.

- Plants cycle water in ecosystems through photosynthesis, respiration, and transpiration.

LO: Diagram the flow of water through an ecosystem, incorporating photosynthesis, respiration, and transpiration.

- Plants are central to the global carbon cycle through photosynthesis.

LO: Estimate the impact of a reforestation and/or deforestation project of 1 million hectares on the global carbon cycle.

- Plants participate in cycling nitrogen and other nutrients.

LO: Evaluate the nitrogen runoff into watersheds from fields of nitrogen-fixing crops versus fields of crops fertilized with inorganic nitrogen.

2C: Ecosystem Dynamics, Functioning, and Resilience. *What happens to ecosystems when the environment changes?*

- Resilience of ecosystems depends on the diversity of plant species.

LO: Evaluate a current research paper on how plant diversity affects ecosystem resiliency after a disturbance.

- Plant populations are affected by environmental changes, which alter ecosystems.

LO: Consider a situation in which population size or distribution of plants is altered due to changes in climate, herbivore populations, or invasive species, and predict how this might affect other aspects of the ecosystem.

3. Heredity: Inheritance and Variation of Traits. Like other organisms, plants use DNA to store genetic information and encode proteins, which underlie the plant's traits. Genes containing DNA are organized into chromosomes and variants of a given gene are called alleles. Each cell of a plant contains a complete set of chromosomes, and the same genetic information. As in other organisms, plants transmit their genetic information from parent to offspring, and from parent cell to daughter cell. Inheritance of chromosomes from parent to offspring explains why offspring have traits that resemble the traits of their parents. Mutations also cause variation in traits, which may be harmful, neutral, or occasionally advantageous for an individual.

3A: Variation of Traits. *Why do individuals of the same species vary in how they look and behave?*

- Some natural populations of plants vary widely in their phenotypes.

LO: Identify a trait in a natural population of plants, then collect and analyze phenotypic data to determine how much the trait varies.

- Gene expression in plants is controlled by genetic and environmental cues.

LO: Analyze data from an online repository of gene expression data to determine how genetic differences or environmental cues affect patterns of gene expression.

LO: Design and conduct an experiment to compare the expression of a gene of interest under different environmental conditions.

LO: Predict differences in gene expression in mutant versus wild-type plants based on the function of the gene.

3B: Inheritance of Traits. *How are characteristics of one generation related to the previous generation?*

- Plants can exist in haploid, diploid, and polyploid states.

LO: Design an experiment to determine the ploidy of a plant tissue.

- Plants vary in their reproductive strategies. Some self-fertilize, which can lead to offspring that are genetically similar. Others have mechanisms to ensure transfer of gametes between different plants, which results in novel genetic combinations.

LO: Compare the genetic diversity of the offspring of a plant that is reproducing sexually versus asexually.

- Some plants can reproduce asexually, producing offspring that are genetically identical to each other and to the parent.

LO: Compare the amount of genetic variation in the offspring of a plant that self-fertilizes and a plant that reproduces asexually.

- Some plants can hybridize within and between species, which can result in novel traits in the offspring.

LO: Select an example of within species hybridization (e.g., hybrid corn) and explain why this can result in desirable agricultural traits.

LO: Diagram the flow of chromosomes from plants of two different species that hybridize to their offspring; construct an argument for whether the offspring will reproduce.

LO: Select a crop plant that is the result of hybridization and subsequent polyploidy (e.g., wheat or banana) and discuss how polyploidy corresponds with important agricultural traits.

4. Biological Evolution: Unity and Diversity. Like all organisms, plants evolved from a single celled organism and continue to evolve. The fossil record of plants and many characteristics of living plants provide strong evidence for evolution. For example, plants use the same genetic code as other organisms, providing evidence for a single origin of life. Like other eukaryotic organisms, plants have mitochondria and a nuclear envelope. Plants also have chloroplasts, which resulted from the endosymbiosis between a eukaryotic cell and a photosynthetic bacterium. Diversity of plants is especially critical in the face of global climate change; plants and other photosynthetic organisms have the capacity to reverse increases in atmospheric carbon dioxide levels. The important roles that plants play in human life as food, feed, fuel, fiber, shelter, and pharmaceuticals have shaped human civilization. The evolution of plants is affected by humans, and affects humans.

4A: Evidence of Common Ancestry and Diversity. *What evidence shows that different species are related?*

- Plants have many genes and gene families in common with all other organisms.

LO: Using gene trees, support the argument that plants have many genes and gene families in common with all other organisms.

- All plants have chloroplasts with similar structure and pigment composition; this is the result of a single endosymbiotic event between a eukaryotic cell and an ancestral cyanobacterium.

LO: Analyze the structural and biochemical evidence for the claim that a single endosymbiotic event between a eukaryotic cell and a cyanobacterium was ancestral to all chloroplasts, including chloroplasts in algal groups.

LO: Formulate an evolutionary hypothesis that accounts for the both the similarities and differences among the chloroplasts of red algae, brown algae, green algae, and land plants, including differences in the number of membranes.

- Plants have multicellular haploid and multicellular diploid stages in their life cycles.

LO: Draw a generic plant life cycle indicating the role of meiosis and mitosis in establishing multicellular haploid and multicellular diploid stages.

LO: Contrast the relative size of the multicellular haploid stage in mosses, ferns, and angiosperms.

- DNA sequences have helped establish the relationships among major plant clades and between plants and other organisms.

LO: Use a computational phylogenetic tool and DNA sequences of one or more genes to predict the evolutionary relationships among major plant clades or between plants and other organisms.

4B: Natural Selection. *How does variation among plants affect survival and reproduction?*

- Diversity of organisms at the chromosome and gene level can be generated in several ways, including recombination, mutation, hybridization, and polyploidy, resulting in the variation underlying evolution by natural selection.

LO: Compare the relative contributions of recombination, mutation, hybridization, and polyploidy to plant diversity.

LO: Explain the biological constraints for hybridization and polyploidy to successfully increase plant diversity.

- Diversity among plants may be influenced by factors such as epigenetics (i.e., structural rather than sequence level changes in DNA) that affect the way genes are expressed.

LO: Explain how epigenetic phenomena such as DNA methylation and histone modification lead to phenotypic variation among plants that are otherwise genetically identical.

- Some plant species can survive a diverse and changing environment. Others cannot, which results in their extinction.

LO: For various species that exhibit a range of diversity, predict some possible outcomes of expansion of their distribution due to climate change.

LO: If a new pathogen or herbivore is introduced, predict possible outcomes for a plant species, relative to its diversity.

4C: Adaptation. *How does the environment influence populations of plants over multiple generations?*

- Adaptation of plants to a variety of environments on Earth has resulted in a great diversity of structures and physiological processes.

LO: Categorize symbiotic relationships that have adapted plants to life in a terrestrial environment.

LO: Compare strategies that have evolved for population migration and dispersal in mosses, ferns, gymnosperms, and angiosperms.

LO: Select and evaluate an adaptation in plants for retaining water while facilitating gas exchange.

LO: For an aquatic plant, select, and evaluate an adaptation for retaining gases needed for photosynthesis.

LO: Compare structures and their modifications in desert plants from the southwestern U.S. and South Africa.

4D: Biodiversity and Humans. *What is biodiversity, how do humans affect it, and how does it affect humans?*

- Diversity of plant species is important for the long-term health of an ecosystem.

LO: Analyze data from a recent paper on ecosystem biodiversity and evaluate the authors' conclusions.

- Human activity has affected global plant diversity, especially through the alteration of habitats.

LO: Using Long Term Ecological Research (LTER) data sets, examine historical and current biodiversity data for a particular region and illustrate how the physical environment and biodiversity have changed as a result of human activity.

- Human selection has affected almost every aspect of crop plants, including their structure, reproduction, genetics, and adaptation.

LO: For a given crop plant (corn, *Brassica*, wheat, soy, potato, tomato, bean, banana, etc.) compare its structure, reproduction, genetics, and adaptation relative to its wild ancestors.

LO: Select a crop plant (e.g., corn, rice, potato) and trace the evolutionary changes that occurred through human domestication of the wild relative.

- Agriculture shapes human populations, including their size, distribution, and cultures.

LO: Compare the size, distribution, and culture of a human population before and during the introduction of agriculture.

LO: Compare the size, distribution, and culture of a human population as agriculture became more sophisticated after 1900.