James D. Mauseth

Botany

SIXTH EDITION

An Introduction to Plant Biology

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University of Texas at Austin

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PREFACE

The preparation of this *Sixth Edition* of *Botany* had two objectives: first, to emphasize the interactions between plants and other organisms, and second, to make plant biology more accessible and relevant to students and other readers.

The emphasis on plant interactions with the biosphere began several editions ago, as the reality of global climate change became clear. Previous editions explored the role of plants in the removal of greenhouse gases and also the loss of many forests by human activities. While thinking about the interrelationships of plants and people, I suspected that students would be interested in the ways in which plants interact with all other organisms. I believe it is more realistic and engaging to examine plant biology as one aspect of the set of all the interactions of organisms and Earth. To take a reductionist view of plant biology as just the anatomy, metabolism, and evolution of isolated plants is to miss out on many of the richest aspects of plant biology.

Consequently, in this *Sixth Edition*, a new *Chapter 26: Community Ecology* has been added to introduce students more fully to interactions between plants and their surroundings. Also, several existing chapters have had new material added to emphasize these interactions; for example, there is a new discussion about ways in which plants detect attacks by fungi in *Chapter 14*: *Development and Morphogenesis*.

Making plant biology more accessible to students and everyone else was the reason I originally began writing this book 30 years ago. It has also been a primary concern in every new edition. Some reviewers and professors have felt that previous editions of *Botany* were too difficult for their students, and, to address their concerns, I have added a new *Chapter 2: Overview of Plant Life*. This is structured to provide a broad introduction to topics such as plant structure, metabolism, genetics, diversity, evolution, and ecology. An entire chapter was dedicated to this so that fundamental principles could be presented with just enough depth and breadth that any student or reader would obtain enough of an overview to feel ready to tackle any other part of the text. Many students will already be so familiar with plants that certain portions of *Overview* will be unnecessary, but they might benefit from other parts. For some students, all of *Overview* may be a valuable aid. Either way, it is meant to welcome everyone into the world of plant biology. I want all people to feel included in this book; I do not want any part to be a barrier to anyone.

Several other elements make this *Sixth Edition* more accessible. First, a *Pronunciation Guide* has been added for those words that have made many of us feel uncertain: people will feel more comfortable with *xylem*, *allele*, or *Rosaceae* if they are confident they are pronouncing these words correctly. Also, every chapter now opens with two new elements, a list of *Learning Objectives* and a few *Did You Know?* facts. The first is designed to allow students to see the important topics immediately, the second is designed to attract their interest. All chapters now end with a new section entitled *At the Next Level*, which presents more advanced topics that some students might want to explore on their own.

A new *Chapter 24: Ethnobotany: Plants and People* has been added to both emphasize interactions between plants and other organisms (us humans) and to make the book more relevant to each reader's life. Among the typical topics such as food and fibers, *Box 24-3 Plants and People: Natural Drugs, Endangered Species, and Women's Rights* discusses modern ethnobotanical problems that result from our increasing knowledge of plants and the cures they may provide. This new chapter does not replace the numerous *Plants and People* boxes that have been developed in previous editions; those are all still present here.

One of the aims of this book is to encourage students to think about the intersection between the scientific world and themselves, including their religious beliefs. This has been an important part of *Botany* from the very first edition with the sections *The Scientific Method* and *Areas Where the Scientific Method is Inappropriate*. In this *Sixth Edition*, *Box 2-4 Botany and Beyond: Noah's Flood and Population Biology* points out that studies of the *Bible* led directly to the establishment of two critically important scientific disciplines: population biology and demography. *Box 17-1 Botany and Beyond: Species Are Populations, Not Types* discusses how our modern concept of species has changed from our original concept that had been based on *Genesis*. The relationships between science and religion are touched on only occasionally, but I do not want students to think there is a complete gulf between their biology classes and their religious lives. Perhaps some instructors will use these sections of *Botany* to lecture more expansively on science and religion.

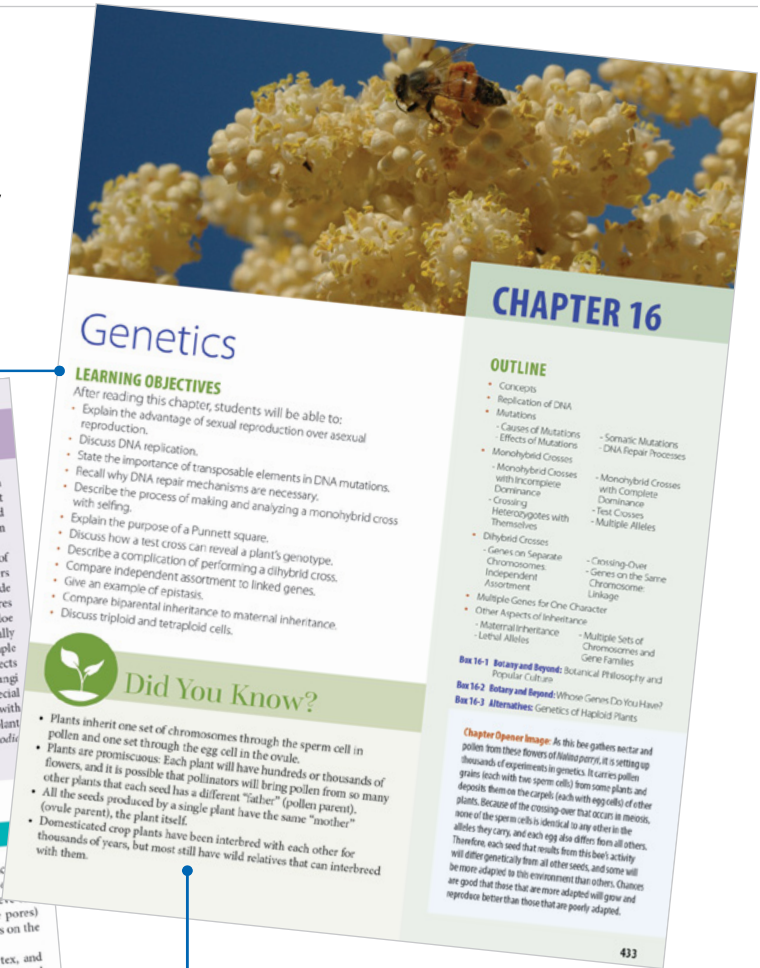
My ultimate goal is to teach about life in general. Every topic mentioned in this book should help the reader to more fully understand human biology, indeed to understand all of biology. No organism exists isolated from all others; instead we all share one biology that encompasses all organisms. We are all in this together.

THE STUDENT EXPERIENCE

The sixth edition of *Botany: An Introduction to Plant Biology* was designed with the student in mind and is packed full of features and elements to help engage, elaborate, and enhance the learning experience.

New to This Edition

Learning Objectives New to this edition, every chapter opens with a list of *Learning Objectives* that allow students to review the important concepts they will encounter in the chapter. Students should review this list prior to digging into the chapter to help guide their focus. As they progress through the material, they should periodically flip back to the *Learning Objectives* to ensure they are fully grasping that chapter's key botanical concepts.



CHAPTER 16

Genetics

LEARNING OBJECTIVES

After reading this chapter, students will be able to:

- Explain the advantage of sexual reproduction over asexual reproduction.
- Discuss DNA replication.
- State the importance of transposable elements in DNA mutations.
- Recall why DNA repair mechanisms are necessary.
- Describe the process of making and analyzing a monohybrid cross with selfing.
- Explain the purpose of a Punnett square.
- Discuss how a test cross can reveal a plant's genotype.
- Describe a complication of performing a dihybrid cross.
- Compare independent assortment to linked genes.
- Give an example of epistasis.
- Compare biparental inheritance to maternal inheritance.
- Discuss triploid and tetraploid cells.

Did You Know?

- Plants inherit one set of chromosomes through the sperm cell in pollen and one set through the egg cell in the ovule.
- Plants are promiscuous: Each plant will have hundreds or thousands of flowers, and it is possible that pollinators will bring pollen from so many other plants that each seed has a different "father" (pollen parent).
- All the seeds produced by a single plant have the same "mother" (ovule parent), the plant itself.
- Domesticated crop plants have been interbred with each other for thousands of years, but most still have wild relatives that can interbreed with them.

OUTLINE

- Concepts
- Replication of DNA
- Mutations
  - Causes of Mutations
  - Effects of Mutations
  - Somatic Mutations
  - DNA Repair Processes
- Monohybrid Crosses
  - Monohybrid Crosses with Incomplete Dominance
  - Crossing Heterozygotes with Themselves
  - Monohybrid Crosses with Complete Dominance
  - Test Crosses
  - Multiple Alleles
- Dihybrid Crosses
  - Genes on Separate Chromosomes: Independent Assortment
  - Crossing-Over
  - Genes on the Same Chromosome: Linkage
- Multiple Genes for One Character
- Other Aspects of Inheritance
  - Maternal Inheritance
  - Lethal Alleles
  - Multiple Sets of Chromosomes and Gene Families

Box 16-1 Botany and Beyond: Botanical Philosophy and Popular Culture

Box 16-2 Botany and Beyond: Whose Genes Do You Have?

Box 16-3 Alternatives: Genetics of Haploid Plants

Chapter Opener Image: As this bee gathers nectar and pollen from these flowers of *Nolina parryi*, it is setting up thousands of experiments in genetics. It carries pollen grains (each with two sperm cells) from some plants and deposits them on the carpels (each with egg cells) of other plants. Because of the crossing-over that occurs in meiosis, none of the sperm cells is identical to any other in the alleles they carry, and each egg also differs from all others. Therefore, each seed that results from this bee's activity will differ genetically from all other seeds, and some will be more adapted to this environment than others. Chances are good that those that are more adapted will grow and reproduce better than those that are poorly adapted.

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Did You Know? New *Did You Know?* feature opens every chapter and illuminates the direct application of plants to students' lives. This list of interesting facts stimulates curiosity about the fascinating botanical world around us, making plant biology more accessible and relevant to students.

At the Next Level

1. *Extreme modification of shoots.* All seed plants have the same basic organization of their shoots, but in some, the various tissues are highly modified. Although cacti appear to be exceptional, they have all the normal parts presented in this chapter; you now know enough to understand papers about their anatomy. Parasitic plants that live entirely within their hosts usually have such highly modified bodies that some organs and tissues are missing or barely recognizable. Species you might find informative are *Rafflesia arnoldii*, *Tristerix aphyllus*, *Viscum minimum*, and *Hydnora africana*. If you really want to go to the next level, look up the family Podostemaceae (sometimes named Podostemonaceae): These are flowering plants in which almost all aspects of anatomy are abnormal.
2. *Evolution and ecology of xylem.* All organisms must obtain, transport, and conserve water. Many studies have analyzed the ways in which alternative types of xylem cells affect a plant's adaptation to its habitat. Also the evolution of xylem—from a few simple tracheids in the first plants to the many diverse types of cells present in angiosperm xylem—has been studied extensively and is well-documented. Searching on the key words "xylem evolution" and "xylem ecology" is a good way to start.
3. *Ant plants (myrmecophytes).* A surprising number of plants have stem modifications, such as hollow chambers with tunnels leading to the shoot surface, that provide shelter for animals such as ants and mites. The structures are called domatia (sing.: domatium; pronounced doe MAY shum) and the insects that occupy them typically provide some sort of benefit to the plant. For example ants often patrol the plant and kill any other insects that would attack the plant, and some even clean fungi off the plant. Many also urinate and defecate in special chambers of the domatia, thus providing the plant with nitrogen fertilizer. Search on these keywords: ant plant myrmecophyte, domatium, *Hydnophytum*, *Myrmecodia*, *Solanopteris* (and check the index of this book).

SUMMARY

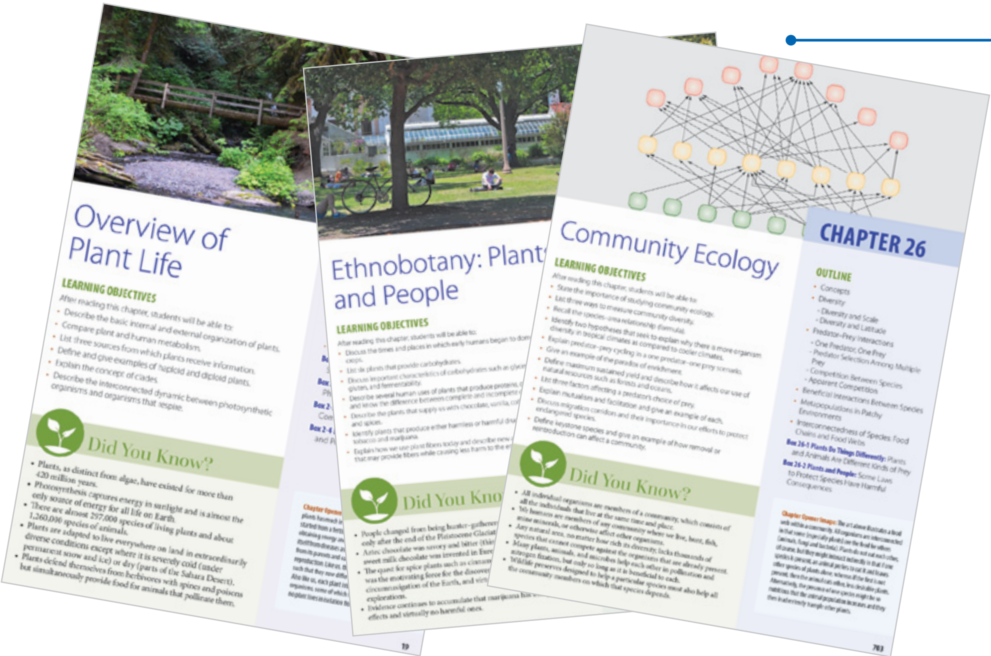
1. Cells must be arranged in the proper patterns and with the proper interrelationships in order to function efficiently.
2. All angiosperms have roots, stems, and leaves, although each can be highly modified in particular environments.
3. Virtually all stems function in producing and supporting leaves and transporting water, minerals, and sugars between leaves, buds, and roots. Other stems are involved in storage, reproduction, dissemination, and surviving stress.
4. All stems consist of nodes and internodes, and they have leaves and axillary buds. Numerous types of stems exist; most individual plants have two or three types of shoots.
5. The three basic types of plant cells, based on walls, are parenchyma (responsible for most metabolism), collenchyma (plastic support), and sclerenchyma (elastic support).
6. The vascular tissues are xylem and phloem. Tracheary elements consist of vessel elements (with perforations) and tracheids (without perforations). Sieve elements consist of sieve cells (with small sieve pores) and sieve tube members (with large sieve pores on the end walls).
7. Stems of all angiosperms have epidermis, cortex, and collateral vascular bundles. In basal angiosperms and eudicots, the bundles occur as one ring surrounding pith, whereas in monocots, they have a complex distribution in conjunctive tissue.
8. Protoxylem and protophloem form while an organ is elongating and therefore must be extensible. Metaxylem and metaphloem form after elongation ceases.
9. Both primary xylem and primary phloem are complex tissues with a variety of cell types, not just conducting cells.

IMPORTANT TERMS

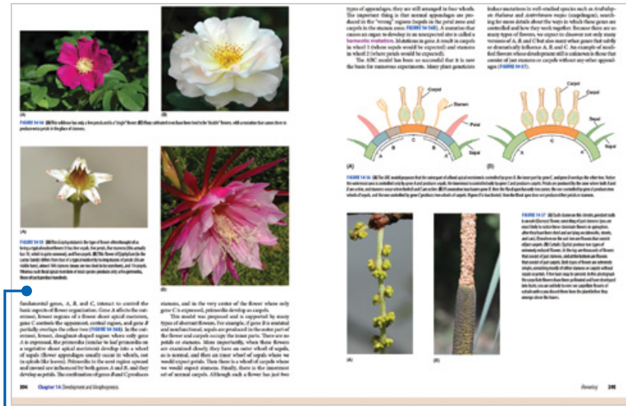
angiosperms	circular bordered pits	cuticle
apical meristem	collenchyma cells	epidermis
axillary bud	companion cells	eudicots
basal angiosperms	corms	fibers
bulbs	cortex	ground meristem

138 Chapter 5: Tissues and the Primary Growth of Stems

At the Next Level New *At the Next Level* feature closes every chapter and provides opportunities for students to expand their understanding of the key botanical concepts they just learned. This feature is especially helpful for higher-level botany courses and biology majors.

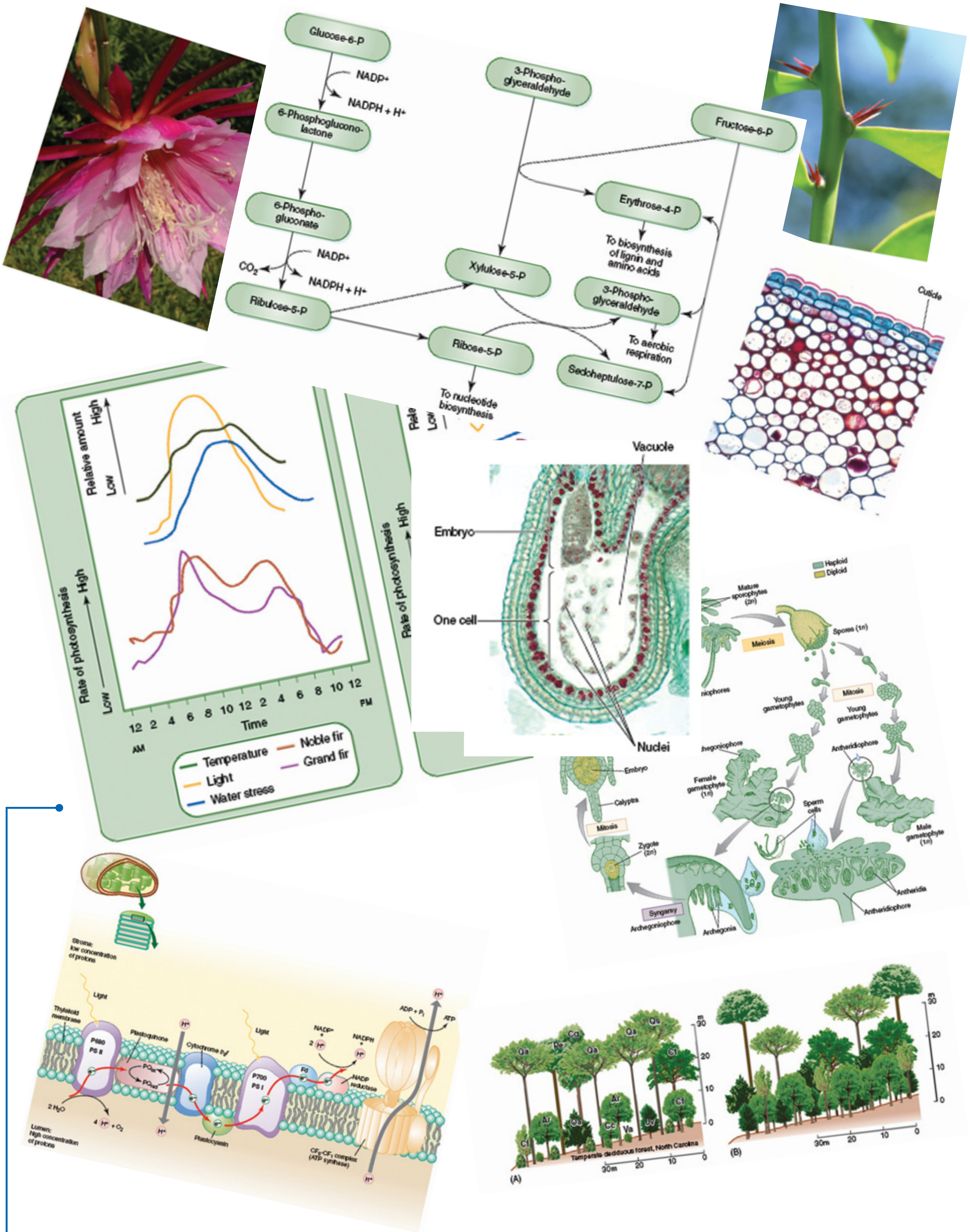


Three New Chapters on Overview of Plant Life, Ethnobotany, and Community Ecology Three new chapters have been added to this edition; *Chapter 2: Overview of Plant Life* provides a broad introduction to plant biology and covers topics such as plant structure, metabolism, genetics, diversity, evolution, and ecology; *Chapter 24: Ethnobotany: Plants and People* emphasizes plant–human relationships and interactions, including information on food plants, plants that provide drugs, and plants that provide fibers, wood, and chemicals; *Chapter 26: Community Ecology* further emphasizes the major theme of this text—the interactions of plants with the biosphere and all other organisms, not just humans.



Interactive eBook Including Web Links Every new print copy of this *Sixth Edition* includes access to a complete and interactive eBook with embedded enhancements such as Web Links and ungraded Knowledge Checks to reinforce key concepts.

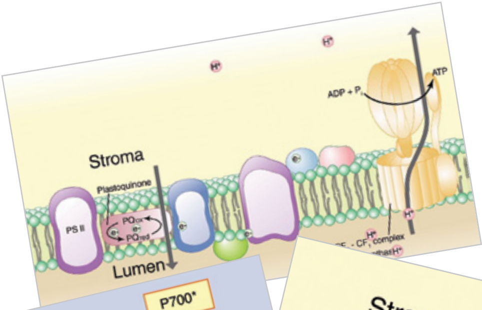
Pronunciation Guide The addition of a *Pronunciation Guide* further improves the accessibility of this edition. Students can feel confident that they are correctly pronouncing certain botanical words such as xylem, allele, and Rosaceae.

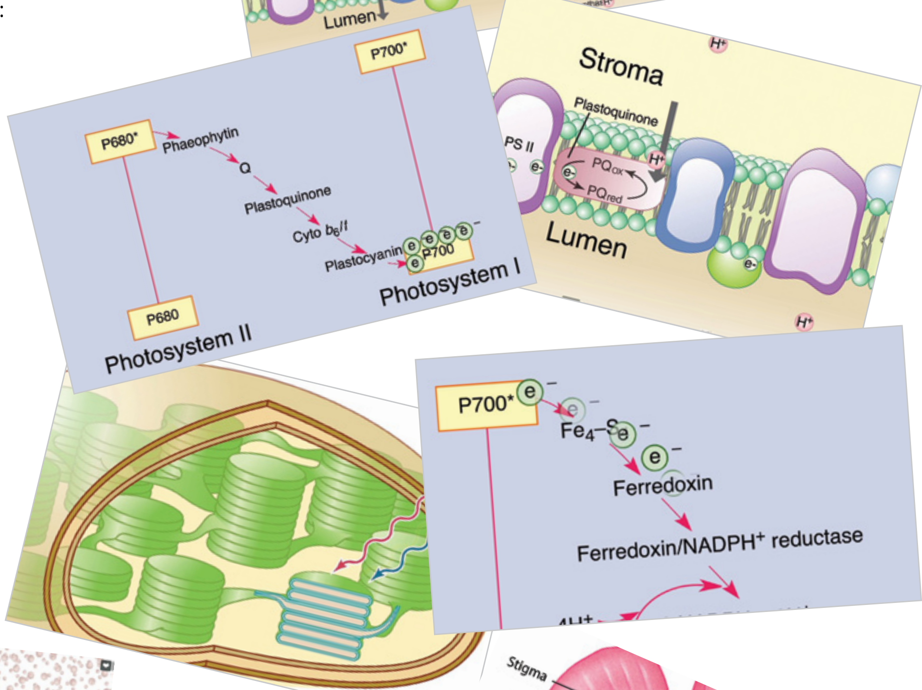


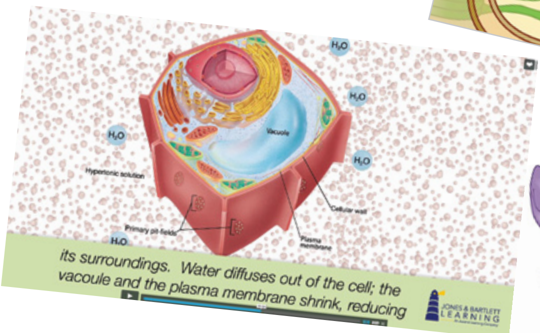
Market-Leading Art and Photos This edition has received a complete overhaul to its art package. It features a visually stunning design with over 550 new and revised figures, including new photographs (most of which were taken by James Mauseth) and thoroughly revised, detailed illustrations that unlock complex topics and biological processes.

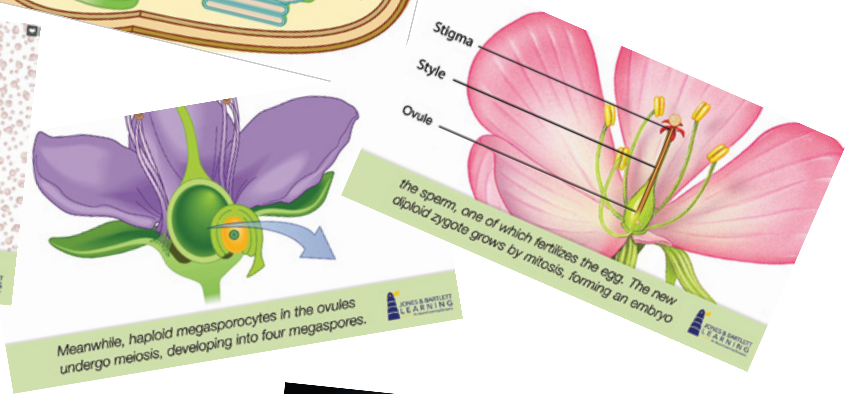
Botany in Action No text connects structure to function better than Mauseth's *Botany*. Building on this strength and new to the *Sixth Edition* is Botany in Action, a collection of high-quality animations on market-selected topics, including:

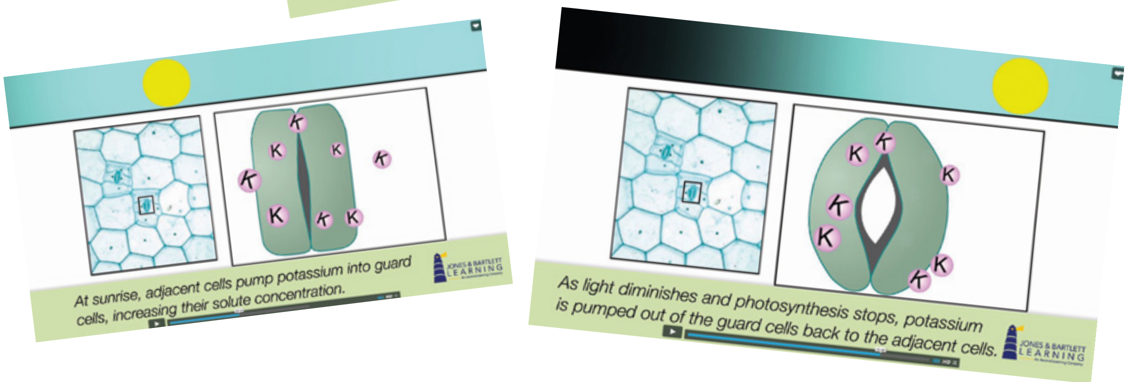
- Photosynthesis
- Water Movement
- Calvin Cycle
- Respiration
- Flowers and Reproduction
- Growth of Wood
- Primary and Secondary Growth
- Pressure Laws Sequence





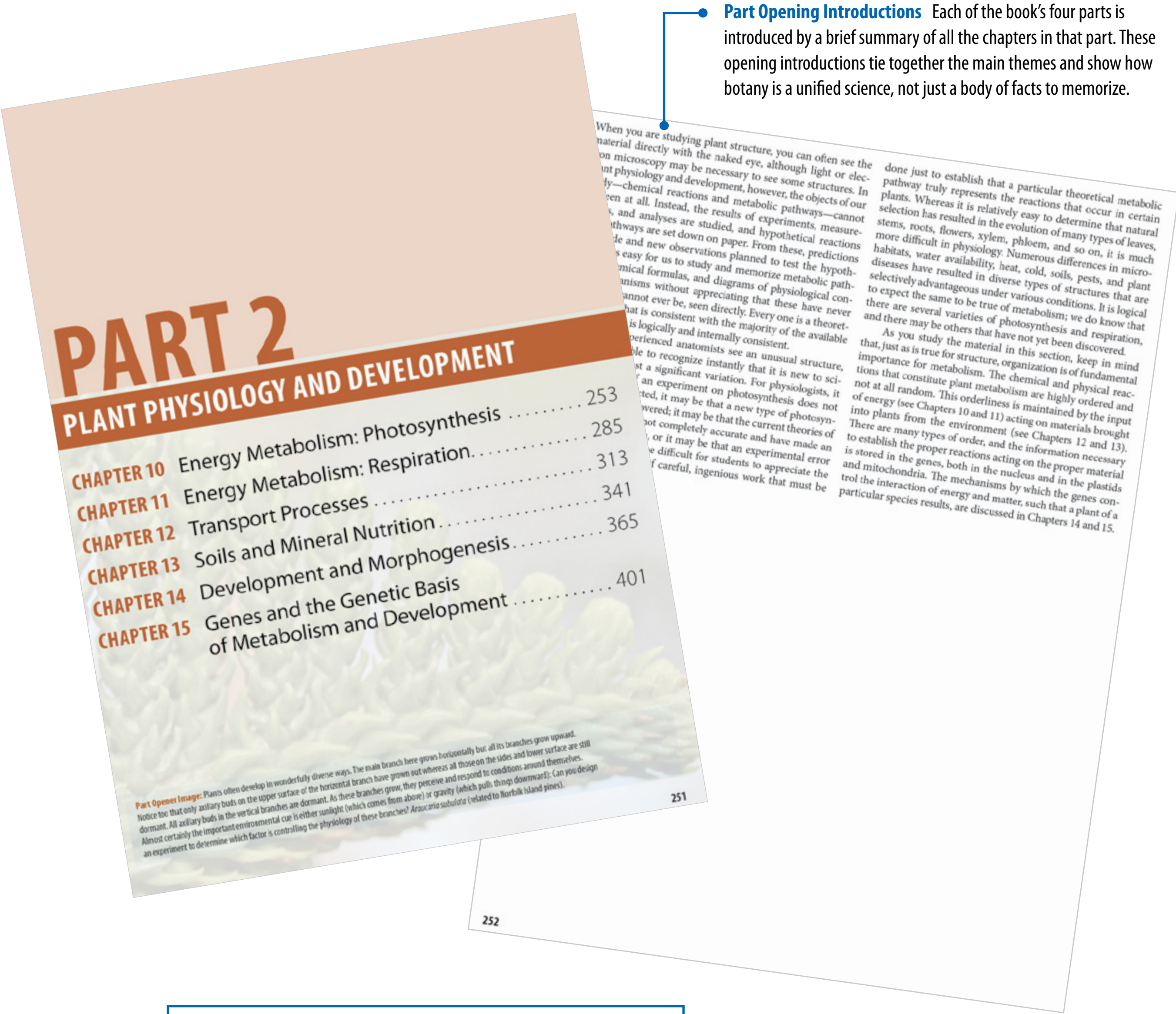






Classic Features

Part Opening Introductions Each of the book's four parts is introduced by a brief summary of all the chapters in that part. These opening introductions tie together the main themes and show how botany is a unified science, not just a body of facts to memorize.


PART 2
PLANT PHYSIOLOGY AND DEVELOPMENT

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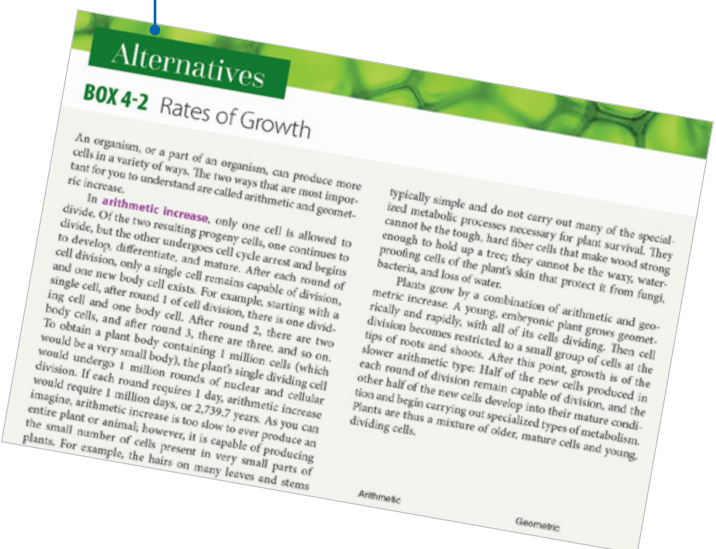
Alternatives Boxes The Alternatives boxes show students they should think expansively. While the text describes the most common, typical aspects of plant biology, there are alternative types that are more advantageous in certain conditions.


Alternatives

BOX 4-2 Rates of Growth

An organism, or a part of an organism, can produce more cells in a variety of ways. The two ways that are most important for you to understand are called arithmetic and geometric increase.

Plants Do Things Differently

BOX 3-2 Calcium: Strong Bones, Strong Teeth, but Not Strong Plants

Most plants and animals need hard parts. Wood is strong enough to support the weight of a tree, and bones play a similar role in animals. Seeds are often protected by resistant shells such as those of walnuts and almonds, and animal shells protect clams and oysters. Our teeth are so tough that they can chew through almost anything. Although plants and animals use hard parts for similar roles, plants rely on thick, tough cell walls, whereas animals use calcium salts.

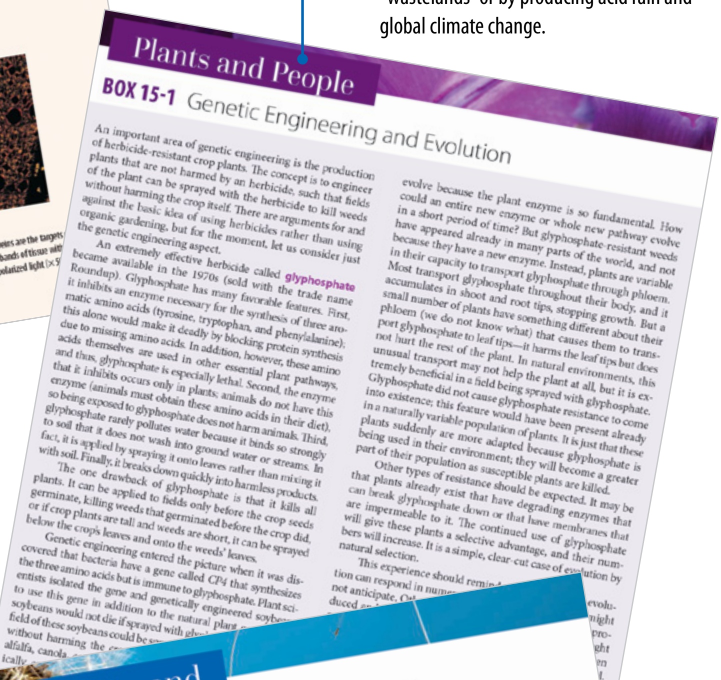
Would it be possible for plants to use bone-like material? We can analyze this as a set of alternatives and their consequences. The present alternative—wood—consists of cellulose and a chemical called lignin. Both are carbohydrates that a plant itself makes through photosynthesis, and thus, they are readily available. And both are remarkably inert, having little impact on other aspects of the plant's metabolism. In contrast, calcium and its salts participate in many metabolic pathways, and building or resorbing shells, bones, or teeth has a broad impact on cell physiology. Shells consist of calcium carbonate, and as animals use carbonate ion (CO_3^{2-}) to build a shell, the acidity of the protoplasm is altered. Furthermore, animals can digest part of their shells if they need the calcium elsewhere, and this liberation of carbonate will again affect the pH. This is tolerable for marine organisms because they use carbonate from the surrounding seawater rather than from their own protoplasm so their pH is not affected. If the shell is resorbed later, the liberated carbonate is likewise dumped outside the animal into the seawater.

Animals like us—with an internal skeleton—use calcium phosphate in our bones and teeth. Calcium carbonate's tendency to alter pH is too dangerous for us, and our skeleton cannot use seawater as a carbonate reservoir. The phosphate ion (PO_4^{3-}) that

FIGURE B3-2 (A) A leaf clearing of maidenhair tree (*Ginkgo*), showing several red-stained leaf veins that conduct sugars out of the leaf. Such veins are the targets … other sucking insects (×15). (B) The same tissue, in polarized light (×15). (C) A cross-section of *Aristolochia* wood; crystals are present in the two bands of tissue wit… walls, see (D). This is a soft tissue in wood and is the site where sugars and other nutrients are stored (×50). (D) The same tissue as (C), but with polarized light (×5…

Plants Do Things Differently Boxes Retained by popular demand, these boxes help students understand and compare plant biology with human biology. Plants really are doing things very differently from the way we do them.

Plants and People Boxes These boxes discuss ways in which plants and people influence each other. Some plants influence people by producing poisonous or irritating compounds; others produce food, medicine, and beauty. In the other direction, human activities influence plants either directly by habitat destruction and the farming of "wastelands" or by producing acid rain and global climate change.



Plants and People

BOX 15-1 Genetic Engineering and Evolution

An important area of genetic engineering is the production of herbicide-resistant crop plants. The concept is to engineer plants that are not harmed by an herbicide, such that fields of the plant can be sprayed with the herbicide to kill weeds without harming the crop itself. There are arguments for and against the basic idea of using herbicides rather than using organic gardening, but for the moment, let us consider just the genetic engineering aspect.

An extremely effective herbicide called **glyphosphate** became available in the 1970s (sold with the trade name Roundup). Glyphosphate has many favorable features. First, it inhibits an enzyme necessary for the synthesis of three aromatic amino acids (tyrosine, tryptophan, and phenylalanine); this alone would make it deadly by blocking protein synthesis due to missing amino acids. In addition, however, these amino acids themselves are used in other essential plant pathways, and thus, glyphosphate is especially lethal. Second, the enzyme that it inhibits occurs only in plants; animals do not have this enzyme (animals must obtain these amino acids in their diet), so being exposed to glyphosphate does not harm animals. Third, glyphosphate rarely pollutes water because it binds so strongly to soil that it does not wash into ground water or streams. In fact, it is applied by spraying it onto leaves rather than mixing it with soil. Finally, it breaks down quickly into harmless products.

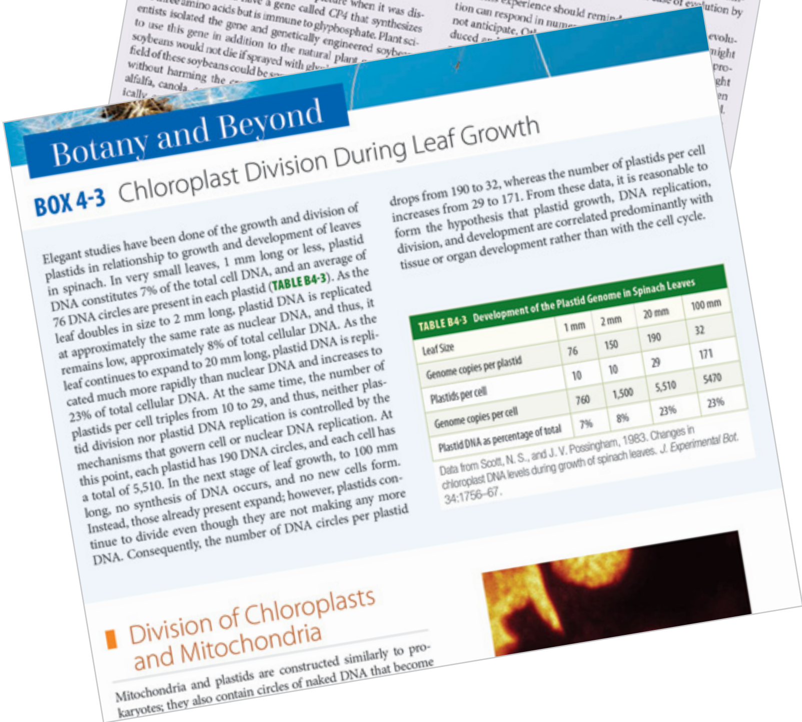
The one drawback of glyphosphate is that it kills all plants. It can be applied to fields only before the crop seeds germinate, killing weeds that germinated before the crop did, or if crop plants are tall and weeds are short, it can be sprayed below the crop's leaves and onto the weeds' leaves.

Genetic engineering entered the picture when it was discovered that bacteria have a gene called *CP4* that synthesizes the three amino acids but is immune to glyphosphate. Plant scientists isolated the gene and genetically engineered soybe… to use this gene in addition to the natural plan… soybeans would not die if sprayed with gly… field of these soybeans could be s… without harming the … alfalfa, canola … ically …

evolve because the plant enzyme is so fundamental. How could an entire new enzyme or whole new pathway evolve in a short period of time? But glyphosphate-resistant weeds have appeared already in many parts of the world, and not because they have a new enzyme. Instead, plants are variable in their capacity to transport glyphosphate through phloem. Most transport glyphosphate throughout their body, and it accumulates in shoot and root tips, stopping growth. But a small number of plants have something different about their phloem (we do not know what) that causes them to transport glyphosphate to leaf tips—it harms the leaf tips but does not hurt the rest of the plant. In natural environments, this unusual transport may not help the plant at all, but it is extremely beneficial in a field being sprayed with glyphosphate. Glyphosphate did not cause glyphosphate resistance to come into existence; this feature would have been present already in a naturally variable population of plants. It is just that these plants suddenly are more adapted because glyphosphate is being used in their environment; they will become a greater part of their population as susceptible plants are killed.

Other types of resistance should be expected. It may be that plants already exist that have degrading enzymes that can break glyphosphate down or that have membranes that are impermeable to it. The continued use of glyphosphate will give these plants a selective advantage, and their numbers will increase. It is a simple, clear-cut case of evolution by natural selection.

This experience should remin… tion can respond in nume… not anticipate. O… duced …



Botany and Beyond

BOX 4-3 Chloroplast Division During Leaf Growth

Elegant studies have been done of the growth and division of plastids in relationship to growth and development of leaves in spinach. In very small leaves, 1 mm long or less, plastid DNA constitutes 7% of the total cell DNA, and an average of 76 DNA circles are present in each plastid (**TABLE B4-3**). As the leaf doubles in size to 2 mm long, plastid DNA is replicated at approximately the same rate as nuclear DNA, and thus, it remains low, approximately 8% of total cellular DNA. As the leaf continues to expand to 20 mm long, plastid DNA is replicated much more rapidly than nuclear DNA and increases to 23% of total cellular DNA. At the same time, the number of plastids per cell triples from 10 to 29, and thus, neither plastid division nor plastid DNA replication is controlled by the mechanisms that govern cell or nuclear DNA replication. At this point, each plastid has 190 DNA circles, and each cell has a total of 5,510. In the next stage of leaf growth, to 100 mm long, no synthesis of DNA occurs, and no new cells form. Instead, those already present expand; however, plastids continue to divide even though they are not making any more DNA. Consequently, the number of DNA circles per plastid drops from 190 to 32, whereas the number of plastids per cell increases from 29 to 171. From these data, it is reasonable to form the hypothesis that plastid growth, DNA replication, division, and development are correlated predominantly with tissue or organ development rather than with the cell cycle.

TABLE B4-3 Development of the Plastid Genome in Spinach Leaves

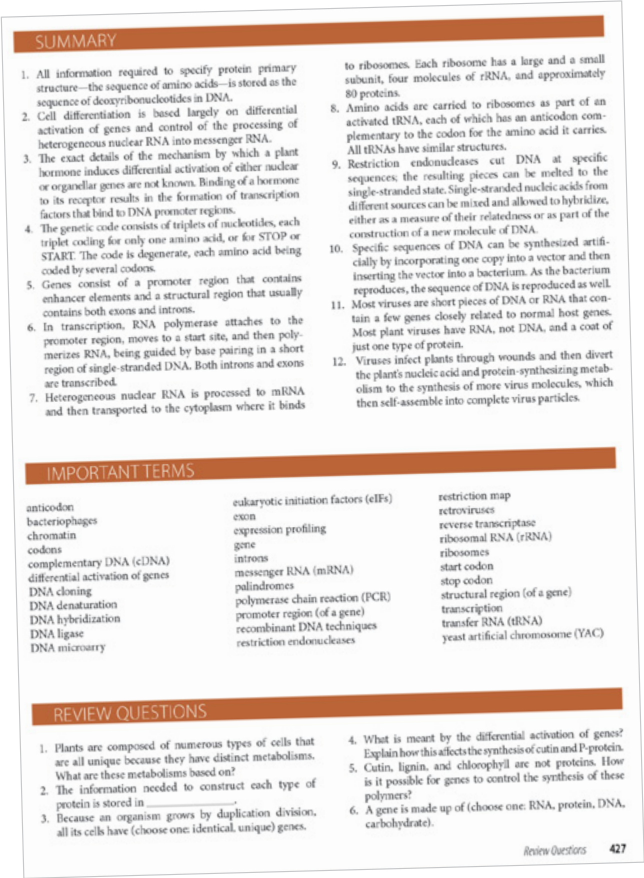
Leaf Size	1 mm	2 mm	20 mm	100 mm
Genome copies per plastid	76	150	190	32
Plastids per cell	10	10	29	171
Genome copies per cell	760	1,500	5,510	5470
Plastid DNA as percentage of total	7%	8%	23%	23%

Data from Scott, N. S., and J. V. Possingham, 1983. Changes in chloroplast DNA levels during growth of spinach leaves. *J. Experimental Bot.* 34:1756–67.

Division of Chloroplasts and Mitochondria

Mitochondria and plastids are constructed similarly to prokaryotes; they also contain circles of naked DNA that become

Botany and Beyond Boxes Modernized to suit a new generation of learners, the popular Botany and Beyond boxes elaborate on subjects that, while not essential to the study of botany, help make the material more relevant and accessible.



SUMMARY

1. All information required to specify protein primary structure—the sequence of amino acids—is stored as the sequence of deoxyribonucleotides in DNA.
2. Cell differentiation is based largely on differential activation of genes and control of the processing of heterogeneous nuclear RNA into messenger RNA.
3. The exact details of the mechanism by which a plant hormone induces differential activation of either nuclear or organellar genes are not known. Binding of a hormone to its receptor results in the formation of transcription factors that bind to DNA promoter regions.
4. The genetic code consists of triplets of nucleotides, each triplet coding for only one amino acid, or for STOP or START. The code is degenerate, each amino acid being coded by several codons.
5. Genes consist of a promoter region that contains enhancer elements and a structural region that usually contains both exons and introns.
6. In transcription, RNA polymerase attaches to the promoter region, moves to a start site, and then polymerizes RNA, being guided by base pairing in a short region of single-stranded DNA. Both introns and exons are transcribed.
7. Heterogeneous nuclear RNA is processed to mRNA and then transported to the cytoplasm where it binds to ribosomes. Each ribosome has a large and a small subunit, four molecules of rRNA, and approximately 80 proteins.
8. Amino acids are carried to ribosomes as part of an activated tRNA, each of which has an anticodon complementary to the codon for the amino acid it carries. All tRNAs have similar structures.
9. Restriction endonucleases cut DNA at specific sequences; the resulting pieces can be melted to the single-stranded state. Single-stranded nucleic acids from different sources can be mixed and allowed to hybridize, either as a measure of their relatedness or as part of the construction of a new molecule of DNA.
10. Specific sequences of DNA can be synthesized artificially by incorporating one copy into a vector and then inserting the vector into a bacterium. As the bacterium reproduces, the sequence of DNA is reproduced as well.
11. Most viruses are short pieces of DNA or RNA that contain a few genes closely related to normal host genes. Most plant viruses have RNA, not DNA, and a coat of just one type of protein.
12. Viruses infect plants through wounds and then divert the plant's nucleic acid and protein-synthesizing metabolism to the synthesis of more virus molecules, which then self-assemble into complete virus particles.

IMPORTANT TERMS

anticodon
bacteriophages
chromatin
codons
complementary DNA (cDNA)
differential activation of genes
DNA cloning
DNA denaturation
DNA hybridization
DNA ligase
DNA microarry
eukaryotic initiation factors (eIFs)
exon
expression profiling
gene
introns
messenger RNA (mRNA)
palindromes
polymerase chain reaction (PCR)
promoter region (of a gene)
recombinant DNA techniques
restriction endonucleases
restriction map
retroviruses
reverse transcriptase
ribosomal RNA (rRNA)
ribosomes
start codon
stop codon
structural region (of a gene)
transcription
transfer RNA (tRNA)
yeast artificial chromosome (YAC)

REVIEW QUESTIONS

1. Plants are composed of numerous types of cells that are all unique because they have distinct metabolisms. What are these metabolisms based on?
2. The information needed to construct each type of protein is stored in ________________.
3. Because an organism grows by duplication division, all its cells have (choose one: identical, unique) genes.
4. What is meant by the differential activation of genes? Explain how this affects the synthesis of cutin and P-protein.
5. Cutin, lignin, and chlorophyll are not proteins. How is it possible for genes to control the synthesis of these polymers?
6. A gene is made up of (choose one: RNA, protein, DNA, carbohydrate).

Review Questions 427

Chapter Summaries To ensure students thoroughly grasp the important concepts, each chapter concludes with a comprehensive Chapter Summary. Students can review the summary before digging into the chapter to direct their study and can also use it as a study tool to prepare for course lectures and exams.

Important Terms A list of Important Terms is included at the end of every chapter. Furthermore, the terms in the chapter appear in bold to draw the reader's attention. Students should refer to the Important Terms as part of their study to assess their understanding of chapter material.

Review Questions These questions have been designed to act as a study guide, to lead students to the most important points, and to focus students' efforts on mastering the most significant concepts. Every chapter includes 30 to 50 thought-provoking questions.

Glossary A comprehensive Glossary defines major botanical and general biological terms. Each definition is keyed to the chapter where the principal discussion occurred.

GLOSSARY

Numbers after definitions are the chapters where the principal discussions occur. Italicized terms are defined elsewhere in the Glossary.

A

A channel The groove in the ribosome small subunit in which the free amino acid-carrying tRNA occurs. Alternative: *P channel*. 15

A horizon The uppermost soil layer, the zone of leaching. 25

abiotic Refers to things that are not and never have been alive. Compare: *biotic*. 25

abscisic acid A hormone involved in resistance to stress conditions, stomatal closure, and other processes. 14

abscission zone The region at the base of an organ, such as a leaf or fruit, in which cells die and tear, permitting the organ to fall cleanly away from the stem with a minimum of damage. 6

absorption spectrum A graph of the relative ability of a pigment to absorb different wavelengths of light. Compare: *action spectrum*. 10

accessory fruit A fruit that contains nonovarian tissue. Synonym: *false fruit*. Alternative: *true fruit*. 9

accessory pigment A pigment that has an absorption spectrum different from that of chlorophyll *a* and that transfers its absorbed energy to chlorophyll *a*. 10

acid-free paper Paper produced by the kraft method of separating and delignifying fibers; acid-free paper is durable and long lasting. 24

acid rain Rain that has become acidic due to air pollution; it can damage plant cuticle as well as speed the leaching of minerals from soil. 13

actinomorphic Synonym for regular flower; radially symmetrical. 9

action spectrum A graph of the relative rates of reaction of a process as influenced by different wavelengths of light. Compare: *absorption spectrum*. 10

active transport The forced pumping of molecules from one side of a membrane to the other by means of molecular pumps located in the membrane. 3, 12

adaptive radiation Divergent evolution in which a species rapidly diverges into many new species. 17

adenosine triphosphate (ATP) A cofactor that contributes either energy or a phosphate group or both to a reaction; as it does so, it loses either one or two phosphate groups, becoming either ADP or AMP. 10, 11

adult plant A plant that is mature enough to flower. Alternative: *juvenile plant*. 14

adventitious Refers to an organ that forms in an unusual place; refers primarily to roots that form on leaves, nodes, or cuttings rather than on another root. 7

agamospermy A set of methods of asexual reproduction that involve cells of the ovule and result in seeds and fruit. 9

aggregate fruit A fruit that develops from the crowding together of several separate carpels of one flower. Alternatives: *simple fruit* and *multiple fruit*. 9

albuminous cell In gymnosperm phloem, a nurse cell connected to and controlling an enucleate sieve cell. Compare: *companion cell*. 5

albuminous seed A seed that contains large amounts of endosperm. Alternative: *exalbuminous seed*. 9

all-or-none response A situation in which an organism either responds to a stimulus or does not respond; the level of response is not correlated with the level of stimulus. Alternative: *dosage-dependent response*. 14

alleles Versions of a gene that differ from each other in their nucleotide sequences. 16

allelochemic See *allelopathy*. 25

allelopathy The inhibition of germination or growth of one species by chemicals (allelochemics) given off by another species. 25

allopatric speciation Speciation that occurs when two or more populations of one species are physically separated such that they cannot interbreed. Alternative: *sympatric speciation*. 17

alternation of generations A type of plant life cycle in which a diploid spore-forming plant gives rise to haploid gamete-forming plants, which in turn give rise to more diploid spore-forming plants. The generations may be similar morphologically (isomorphic) or dissimilar (heteromorphic). 9, 19–22

amino acid A small molecule containing an amino group and a carboxyl group; the monomers of proteins. 2, 15

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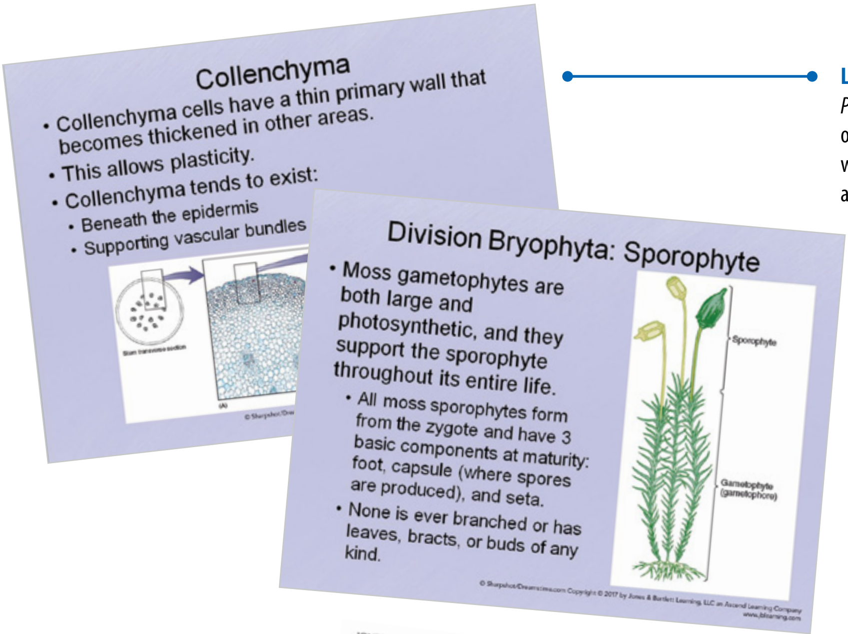
TEACHING TOOLS

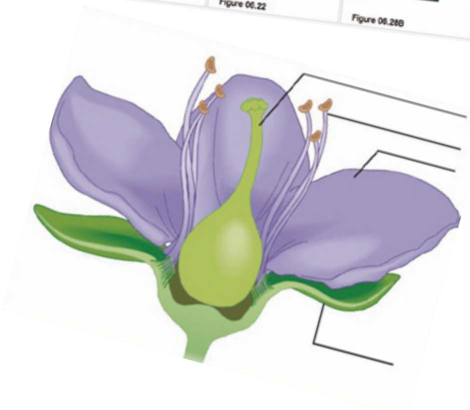
A variety of Teaching Tools assist instructors with preparing for and teaching their courses. These resources are available via digital download and multiple other formats.

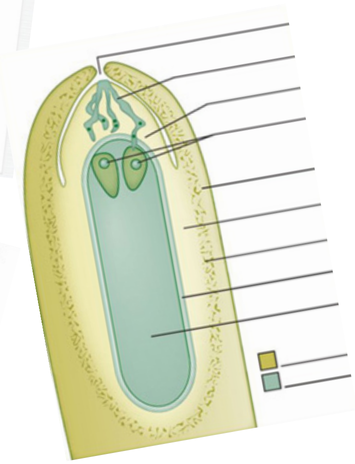


Lecture Outlines in PowerPoint format The *Lecture Outlines in PowerPoint* format provide lecture notes and images for each chapter of *Botany: An Introduction to Plant Biology, Sixth Edition*. Instructors with Microsoft PowerPoint software can customize the outlines, art, and order of presentation.

Instructor's Manual The Instructor's Manual, provided as a text file, includes lecture outlines and teaching tips.

Solutions to Review Questions These files contain answers to all of the end-of-chapter review questions found in the text.





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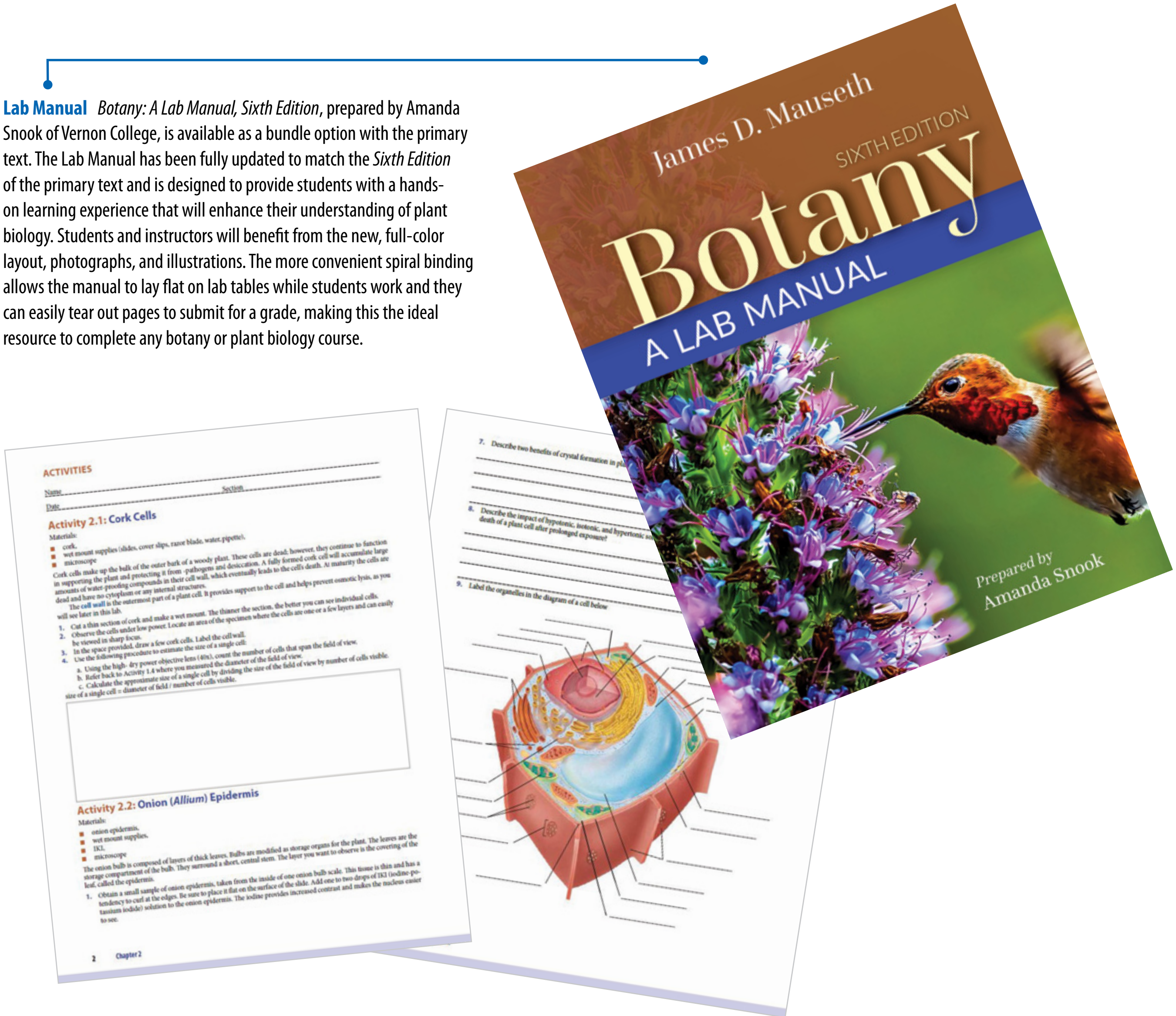
LAB MANUAL

Lab Manual *Botany: A Lab Manual, Sixth Edition*, prepared by Amanda Snook of Vernon College, is available as a bundle option with the primary text. The Lab Manual has been fully updated to match the *Sixth Edition* of the primary text and is designed to provide students with a hands-on learning experience that will enhance their understanding of plant biology. Students and instructors will benefit from the new, full-color layout, photographs, and illustrations. The more convenient spiral binding allows the manual to lay flat on lab tables while students work and they can easily tear out pages to submit for a grade, making this the ideal resource to complete any botany or plant biology course.



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Lab Manual Table of Contents

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James D. Mauseth, PhD
Austin, Texas

ABOUT THE AUTHOR

Jim Mauseth was born in eastern Washington state and spent his childhood on his family's irrigated farm, tending wheat, potatoes, corn, and other crops. Adjacent to the farm was an undisturbed sagebrush desert with a sparse but rich variety of wildflowers. He studied botany at the University of Washington in Seattle, and hiked in the cool, rainy Cascade Mountains, the Olympic Rainforest, and on Mount Rainier. The rocky coast of Puget Sound, with its abundant algae and invertebrates, was also a favorite place.

In 1975, he obtained his PhD and became a professor at the University of Texas and has lived in Austin ever since. The vegetation around Austin includes pine woodland, oak-juniper forest, mesquite scrubland, and open grassland. Representatives of all major groups of plants are present within an hour or two, and the streams contain Chara, an alga closely related to true plants. The swamps of Louisiana and the desert of Big Bend National Park are nearby.

Jim's research at UT centers on the anatomy and evolution of plants that have highly unusual bodies, such as cacti and parasitic plants. Many of these occur in Latin America, and Jim has travelled extensively in South America to study plants. He believes that one of the best ways to observe plants is from the seat of a bicycle, and he has cycled through many parts of the United States (coast-to-coast once), across Alaska, and through much of Europe.

As a professor, he has taught both Introductory Botany as well as Plant Anatomy every year since 1975. Many students, both graduates and undergrads, have assisted in his research. He knows from this long experience that students today are just as talented, capable, and interested as students half a century ago.

PRONUNCIATION GUIDE

abiotic	AY bye otic	
abscisic (acid)	ab SIZE ick	or ab SIZ ick (SIZ as in sizzle)
actinomorphic	ack tin oh MORE fick	
adenosine	a DEN oh seen	(a as in adverse)
adventitious	ad ven TI shush	
allele	al EEL	(the final e is silent; not al EEL ee)
allelochemic	al eel oh KEM ick	
allelopathy	al EEL oh pathy	or al eel oh PATH ee
androecia	an droh EE see uh	
androecium	an droh EE see um	
angiosperm	AN gee oh sperm	
angiospermous	an gee oh SPERM us	
anion	AN eye on	(not AN yun)
anisogamy	AN eye so gam ee	or an eye SAW gam ee
antheridia	anther ID ee uh	
antheridiophore	anther ID ee oh for	
antheridium	anther ID ee um	
antipodal	an TI poad uhl	(poad like road)
apomorphy	AP oh more fee	(ap as in apple)
apoplast	A po plast	(a as in adverse)
archaebacterium	ar key bact IR ee um	
archegonia	arch eh GON ee uh	
archegoniophore	arch eh GON ee oh four	
archegonium	arch eh GON ee um	
aril	AIR ill	
atactostele	ay TACT oh steel	
axoneme	AX oh neam	(neam as team)
biome	BUY ohm	
biotic	buy AW tick	
biotroph	BUY oh troph	(troph as in loaf)
bryophyte	BRY oh fight	(bry as in dry)
calyces	KAY li sees or KAL i sees	
calyx	KAY licks	
cation	CAT eye on	
charophyte	KAR oh fight	
chiasma	key AHS muh	
chitin	KAI tin	
chlamydospore	klam IH doh spoar	
cilia	SILLY uh	
cilium	SILL ee um	
circadian	sur KAY di un	
coenocyte	SEEN oh sight	
coenzyme	KOH en zyme	
coevolution	koh ev ol OU shun	
coleoptile	coal ee OP tile	
collenchyma	kol EN kim uh	
crista	KRIS tah	
cristae	CHRIS tee	
cuticle	KIU tih kl	
cutin	KIU tin	
cytokinesis	sight oh kai NEE sis	
cytokinin	sight oh KAI nin	
dibiontic	dye bye ON tik	
dichotomous	dye KOT oh mus	
dicot	DYE kot	
dioecy	dye EE cy	
endophyte	END oh fight	
epiphyte	EPI fight	
eudicot	you DIE kot	
eukaryote	you KAR ee oat	
euphyllophyte	you FILL oh fight	
eustele	YOU steel	
flagellum	fla- GEL um	
gamete	GAM eat	
gametophore	gam EAT oh four	
gametophyte	gam EAT oh fight	
gene	jean	
genera	GEN er uh	
genome	JEAN ohm	
genotype	JEAN oh type	
genus	JEAN us or GEE nus	
gibberellin	jib er ILL in	
gymnosperm	JIM no sperm	
gynoecium	jah een EE see um	
hila	HIGH lah	

hilum	HIGH lum	
homeotic	home ee AH tik	
hypha	HIGH fuh	
hyphae	HIGH fee	
isogamy	eye SAW gam ee	
leucoplast	LOU koh plast	
lignophyte	LIG noh fight	
lysis	LIE sis	
lysosome	LIE soh soam	
manoxylic	man oh ZY lik	
meiosis	my OH sis	
mitosis	my TOE sis	
monoecy	mon EE see	
mycorrhiza	my koh RYE zuh	
mycorrhizae	my koh RYE zee	
niche	NI ch (as in rich) or KNEE ch	
oogamy	OH oh gam ee	or oh AH gam ee (each "o" is pronounced)
oogonia	oh oh GON ee uh	
oogonium	oh oh GON ee um	
pangaea	pan GEE uh	
paramylon	pair AM ill on	
parenchyma	par EN kim uh	
perigynous	pair IH jen us	
phage	FAY jj	
phellem	FELL em	
phelloderm	FELL oh derm	
phellogen	FELL oh jen	
phenotype	FEE noh type	
phloem	FLOW em	("o" and "e" are distinct)
phyletic	fi LET ik	("fi" as in high)
phyllode	FILL oad	(oad as in toad)
phyllotaxy	FILL oh tax ee	
phylogenetic	fi low jen ET ik	
phytoalexins	fight oh al EX inz	
phytochrome	FIGHT oh chrome	or fight oh CHROME
phytoferritin	FIGHT oh fer it in	
pleiotropic	ply oh TROH pic	
pneumatocyst	new MAT oh sist	
poikilohydry	poy kil oh HIGH dree	
prokaryote	pro CARRY oat	
protonema	pro tow NEEM uh	
protostele	PRO tow steel	
protoxylem	pro tow ZY lem	
pycnoxylic	pik noh ZY lik	

rachis	RAY kis	
rachises	RAY kis ease	
raphe	RAY f	
raphide	ray FIE d	(fie as in pie)
rhizoid	RYE zoid	(zoid as in Boyd)
rhizome	RYE zoam	(zoam as in foam)
ribose	RYE bose	(bose as in gross)
saprotroph	SAP row troph	(troph as in loaf)
sclereids	SKLER ee id	or SKLER eed
sclerenchyma	skler EN kim uh	
scutellum	skee u TEL um	
seta	SEAT uh	
setae	SEAT ee	
statocyte	STAT oh sight	
statolith	STAT oh lith	
stele	STEAL	
stigma	STIG muh	
stipe	STY p	
stipule	STIP you'll	
stolon	STOW lon	
stoma	STOW muh	
stomata	stow MA ta	or STOW ma ta
strobilus	STROW bil us	(strow as in grow)
stroma	STROW muh	(strow as in grow)
stromatolite	strow MAT oh light	
taxis	TAX sis	
taxon	TAX on	
telome	TEAL ohm	
thylakoid	THIGH la koid	
ti plasmid	TEA EYE plasmid	
tracheary	TRAKE ee ary	(trake as in rake)
tracheid	TRAKE ee id	(trake as in rake)
trichogyne	TRICK oh jyn	(jyn as in mine)
trichome	TRI comb	
tropic response	TROPE ick	(trope as in rope; not as in Tropic of Cancer)
tyloses	tie LOW sees	
tylosis	tie LOW sis	
vacuole	VAK you ol	(ol as in hole)
valance	VAY lance	(vay as in way; not as in valley)
violaxanthin	vi ol uh ZAN thin	
xerophyte	ZERO fight	
xylem	ZY lem	
zoospore	ZOH oh spore	(zoh as in mow, tow, go)
zygote	ZIGH goat	(zigh as in sigh)

CHAPTER 1

Introduction to Plants and Botany

LEARNING OBJECTIVES

After reading this chapter, students will be able to:

- Recognize the relationship between plants and climate change.
- Describe the difficulty in creating a singular definition of a plant.
- List four fundamental tenets of the scientific method.
- Give an example of an area where the scientific method is inappropriate.
- Summarize the fundamental concepts related to the study of plants.
- Order the process of evolution from early prokaryote to plant.
- Provide two examples of plant adaptations.
- Explain the difference between observation and interpretation.

OUTLINE

- Concepts
- Plants
- Scientific Method
- Areas Where the Scientific Method Is Inappropriate
- Using Concepts to Understand Plants
- Origin and Evolution of Plants
- Diversity of Plant Adaptations
- Plants Versus the Study of Plants

Box 1-1 Plants and People: Plants and People, Including Students

Box 1-2 Plants and People: The Characteristics of Life

Box 1-3 Plants and People: Algae and Global Warming

Did You Know?

- Early humans were weaving fibers of flax plants into rough clothing as early as 36,000 years ago.
- Vanilla, chocolate, coffee, tea, cinnamon, and mint are all made from plants.
- Plant products kill tens of thousands of people every year, not only through accidental poisoning but through cancer caused by smoking tobacco.
- Science and the scientific method are a simple set of accepted rules about the ways in which evidence can be gathered and processed.

Chapter Opener Image: People and animals must have oxygen to live. Without oxygen, we would die of asphyxiation. The plants here are photosynthesizing in the sunshine, producing the oxygen we need. The roots of these trees hold the soil in place, even on steep slopes. Without the trees, rain would wash all the soil away leaving just bare rock and this river would flood after every rain or be almost dry when there is a dry period. Global warming is causing less snowfall (and more snow melt) in mountains; this alters river flow and the suitability of the area for plants and animals. Worthington Glacier, Alaska.

Concepts

Earth is becoming hotter, flooding is more frequent, and weather is more violent because we burn coal, oil, and other fossil fuels, which releases carbon dioxide into the atmosphere. Carbon dioxide is one of several greenhouse gases that allow visible sunlight to pass through the atmosphere and strike Earth's surface, heating it. The warmer rocks, soil, and water give off infrared radiation back out toward space, but greenhouse gases absorb infrared light and heat the atmosphere. It is a simple relationship: The higher the concentration of greenhouse gases in the atmosphere, the hotter the climate. As Earth becomes hotter, more water evaporates out of the oceans into the air, where it then falls as heavy rains, causing flooding throughout the world. The warmer air also causes snow and ice on mountain tops to melt faster, increasing flooding. Every summer brings more mudslides in California, larger floods on the Mississippi and other rivers, and more violent tornadoes and hurricanes. This is global warming, also known as global climate change.

What does this have to do with botany? Everything. Plants in the sun photosynthesize; that is, they take carbon dioxide out of the air and use it to make the chemicals that compose their bodies. Most of the weight of leaves, stems, roots, flowers, fruits, and seeds is carbon that was carbon dioxide in the air before plants captured it. As plants photosynthesize, they remove carbon dioxide from the air and lock it into their bodies, helping to keep Earth cool and counteracting the warming we are causing. An important question now is "Can plants remove enough carbon dioxide from the air to counteract the damage we are doing?" The answer is "probably not."

The balance between the addition of atmospheric carbon dioxide by us and its removal by plants is affected by several factors that are easy to understand. All animals, fungi, bacteria, and other nonphotosynthetic organisms produce carbon dioxide just by being alive. As our bodies "burn" our food (technically, as they respire it), carbon dioxide is produced; therefore, animals (including humans) have been adding carbon dioxide to the atmosphere for billions of years. The real problem began when our ancestors discovered fire: We then began burning wood and coal and, more recently, petroleum, natural gas, and other fossil fuels, adding carbon dioxide to the air in huge quantities. Until our mastery of fire, plants were actually taking carbon dioxide out of the air faster than our respiration was adding it.

Photosynthesis originated 2.8 billion years ago, and the amount of carbon dioxide in the air has decreased and Earth has cooled, until the start of the Industrial Revolution when we began burning massive amounts of fuel. If photosynthesis has been removing carbon dioxide from the atmosphere, does that mean there was more carbon dioxide in the air in the past? And, if so, was Earth warmer in the past? The answer to both questions is yes. Earth formerly had much more carbon dioxide in its atmosphere and consequently was much hotter. Earth's climate is changing now, but it has always been changing and has never stayed the same for long periods of time.

In addition to respiration and burning, carbon dioxide is added to the air as volcanoes erupt and as magma (molten rock) comes upward at mid-ocean ridges between the giant tectonic plates that carry the continents on Earth's surface. Carbon dioxide is also removed as certain algae build shells of calcium carbonate: All limestone rock on Earth is composed of vast numbers of microscopic shells of certain algae, clams, and other marine animals. At times in the past volcanoes were very active and added carbon dioxide faster than photosynthesis could remove it, causing Earth to heat up. At other times they were inactive and photosynthesis outpaced volcanism and Earth cooled.

Neither heating nor cooling has ever been severe enough to risk killing all life on Earth. Instead, when Earth was warm, rains were also heavy (because of the warm oceans), so plants grew faster and more abundantly, absorbing more carbon dioxide. When plants take most of the carbon dioxide out of the air, Earth cools and dries, and plant growth slows.

Today, we are at an unusually cool period in Earth's history. Plants have taken so much carbon dioxide out of the air there is almost none to trap the sun's heat. We are actually in an ice age right now, known as the Pleistocene Ice Age, but we are in its warm period (called the Holocene warm period), known as an interglacial period (cold periods of ice ages are called glacials because glaciers are then common on almost all mountains). Is it bad that Earth is unusually cool? Should we be burning even more petroleum and coal to heat it up?

The current coolness is exceptional, but it is the climate in which we evolved and became distinct from the other great apes. It is also the climate in which most of our food plants evolved: Wheat, rye, barley, and corn are grasses that flourish under cool, dry conditions. Grasses grow on open, treeless plains, but when Earth is warm most of its surface is covered by forests, and grasses do not grow well in the shade below trees. You may know that a significant step in the evolution of us modern humans is that, unlike our ancestors who were adapted to living in trees, we gradually evolved to walk upright on the ground, freeing our forelimbs (our arms) such that we could use our hands for holding and manipulating tools. We did not come down out of the trees until open grasslands finally appeared on Earth, and those came about in the last 30 million years as Earth became cooler, drier, and the forests receded, all due to plant photosynthesis.

More recently, we people began to cultivate our own food. Agriculture is new, having separate, independent origins in Europe, Asia, Africa, and the Americas less than about 11,000 years ago. That is a significant number: The current interglacial period we are living in now began only 14,000 years ago. Snow and ice began to melt away, people spread across more of the land, and some humans made the journey from Asia to the Americas at that time. In the very short time of just a few thousand years between 14,000 years ago and 11,000 years ago, humans progressed from being wandering hunter-gatherers to starting the first farms, then establishing villages and towns, and then civilization began with art, writing, religion, and science.

Let's go back to our original question: "What does this have to do with botany?" Again, the answer is everything. Plants changed the climate of Earth such that we can now live on it. Plants also produce the oxygen we breathe and the food we eat. We get cloth, paper, lumber, and chemicals from plants, and plants are important to us spiritually because of their beauty.

As you study the following pages, think of the many ways in which plant biology affects our own biology. And think of other organisms; we share Earth's surface not only with plants but also with all other animals, fungi, and microbes. All our biologies affect those of all other organisms, as we are all interconnected and interdependent.

Plants

Botany is the scientific study of plants. This definition requires an understanding of the concepts "plants" and "scientific study." It may surprise you to learn that it is difficult to define precisely what a plant is. Plants have so many types and variations that a simple definition has many exceptions, and a definition that includes all plants and excludes all nonplants may be too complicated to be useful. Also, biologists do not agree about whether certain organisms—particularly algae—are indeed plants. Rather than memorizing a terse definition, more is gained by understanding what plants are, what the exceptional or exotic cases are, and why botanists disagree about certain organisms.

Your present concept of plants is probably quite accurate: Most plants have green leaves, stems, roots, and flowers (**FIGURE 1-1**), but you can think of exceptions immediately. Conifers such as pine, spruce, and fir have cones rather than flowers (**FIGURE 1-2**), and many cacti and succulents do not appear to have leaves. Both conifers and succulents, however, are obviously plants because they closely resemble organisms that unquestionably are plants. Similarly, ferns and mosses (**FIGURES 1-3** and **1-4**) are easily recognized as plants. Fungi, such as mushrooms (**FIGURE 1-5**) and puffballs, were included in the plant kingdom because they are immobile and produce

FIGURE 1-1 This evening primrose (*Oenothera*) is obviously a flowering plant. It has a short stem and numerous simple leaves; its extensive root system is not visible here.

FIGURE 1-2 Conifers, like this spruce (*Picea*), produce seeds in cones; the conifers, together with the flowering plants and a few other groups, are known as seed plants.

FIGURE 1-3 Ferns have several features in common with flowering plants; they have leaves, stems, and roots; however, they never produce seeds, and they have neither flowers nor wood.

FIGURE 1-4 Of all terrestrial plants, mosses have the least in common with flowering plants. They have structures called "leaves" and "stems," but these are not the same as in flowering plants. They have no roots at all.

(A)

(B) Courtesy of C. Mims, University of Georgia

FIGURE 1-5 Fungi such as **(A)** mushrooms and **(B)** brackets are not considered to be plants. They are never green and cannot obtain their energy from sunlight. Also, their tissues and physiology are quite different from those of plants. Fungi are important to plants, however, because many fungi break down dead material in the soil such as fallen leaves and rotting tree trunks; as the fungi cause these materials to rot, they release minerals and enrich the soil.

spores, which function somewhat like seeds; however, biologists no longer consider fungi to be plants because recent observations show that fungi differ from plants in many basic biochemical and genetic respects.

Algae are more problematical. One group, the green algae (**FIGURE 1-6**), is similar to plants in biochemistry and cell structure, but it also has many significant differences. Some botanists conclude that it is more useful to include green algae with plants; others exclude them, pointing out that some green algae have more in common with the seaweeds known as red algae and brown algae (**FIGURE 1-7**). Arbitrarily declaring that green algae are or are not plants solves nothing; the important thing is to understand the concepts involved and why disagreement exists (**TABLE 1-1**).

All plants have a scientific name. Each name consists of two words: a genus (pronounced GEE nus) name and a specific epithet. For example, the genus *Prunus* has several species with edible fruits, and they are distinguished by their species epithet: Cherries are *Prunus avium*, peaches are *Prunus persica*, and apricots are *Prunus armeniaca*. The name of cherries is not just "*avium*," it is both words: *Prunus avium*. In the scientific names of plants, the genus name is always capitalized but the species epithet is not (it is not *Prunus Avium*). Both words are italicized or underlined. Closely related genera

FIGURE 1-6 These green algae do not look much like plants, but many aspects of their biochemistry and cellular organization are very similar to those of plants. Some green algae were the ancestors of land plants; although not considered to be true plants, they are obviously closely related to plants.

FIGURE 1-7 These brown algae (*Fucus*), commonly called kelp, have very plant-like bodies as a result of convergent evolution: they are not true plants. Their biochemistry, genetics, anatomy, and reproduction differ greatly from those of plants.

TABLE 1-1 The Three Domains of Organisms

Prokaryotes
Domain Archaea
Domain Bacteria (including cyanobacteria)
Eukaryotes
Domain Eukarya
Protista: single-cell organisms (protozoans, algae); multicellular algae
Kingdom Myceteae: fungi such as mushrooms, puffballs, bread mold
Kingdom Animalia: animals
Kingdom Plantae:[1] plants
Division Bryophyta: mosses
Division Pteridophyta: ferns
Division Coniferophyta: conifers
Division Magnoliophyta:[2] flowering plants

[1]Within kingdom Plantae, many botanists recognize about 17 divisions; only the four most familiar are listed here. Many botanists conclude that algae should be included in kingdom Plantae.

[2]Some people use the term Angiospermophyta.

are grouped together into families; in botany, family names are always capitalized and always end in "-aceae" (pronounced as if you are spelling the word "ace": AY see ee). *Prunus* is in the rose family Rosaceae (pronounced rose AY see ee), along with roses (*Rosa*), apples (*Malus*), strawberries (*Fragaria*), and many others. A very few families have old, alternative endings, but those are rarely used. For example, the modern name for the mustard family is Brassicaceae (with the "-aceae" ending); the old family name, Cruciferae, is almost never encountered except in older publications. For animals, family names end in "-ae." We humans are *Homo sapiens* in the family Hominidae; other members of our family are chimpanzees (*Pan*), gorillas (*Gorilla*), and orangutans (*Pongo*).

Scientific Method

The concept of a scientific study can be understood by examining earlier approaches to studying nature. Until the 15th century, several methods for analyzing and explaining the universe and its phenomena were used, with religion and speculative philosophy being especially important. In religious methods, the universe is assumed to either be created by or contain deities. The important feature is that the actions of gods cannot be studied: They are either hidden or capricious, changing from day to day and altering natural phenomena. Agricultural studies would be useless because some years crops might flourish or fail because of weather or disease, but in other years, crop failure might be due to a god's intervention (a miracle) to reward or punish people. There would be no reason to expect consistent results from experiments. In a religious system, much of the knowledge of the world comes as a revelation from the deity rather than by observation and study of the world. A fundamental principle of all religions is faith: People must believe in the god without physical proof of its existence or actions.

Speculative philosophy reached its greatest development with the ancient Greek philosophers. Basically, their method of analyzing the world involved thinking about it logically. They sought to develop logical explanations for simple observations and then followed the logic as far as possible. An example is the philosophical postulation of atoms by Democritus around 400 BCE (before the common era). From the observation that all objects could be cut or broken into two smaller objects, it follows logically that the two pieces can each be subdivided again into two more, and so on. Finally, some size must be reached at which further subdivision is not possible; objects of that size are atoms. But there was no proof, no experiment to determine if that was actually valid. Democritus could have been wrong: For all anyone knew, it might have been possible to continue dividing pieces forever, infinitely. Speculative philosophy did not involve verification; philosophical predictions were made, but no actual experiment or observation was performed to see if they were correct. A speculation is a statement that cannot be proved or disproved (e.g., "If Elvis were still alive, he would still be performing in Las Vegas."). A problem with this method is that often several alternative conclusions are equally plausible logically; only experimentation reveals which is actually true.

Starting before the 1400s, a new method, called the **scientific method**, slowly began to develop. Several fundamental tenets were established:

1. *Source of information. All accepted information can be derived only from carefully documented and controlled observations or experiments.* Claims emanating from priests or prophets—or scientists—cannot be accepted automatically; they must be subjected to verification and proof. For example, for hundreds of years, medicine was taught using a text called *Materia Medica* written by Galen, a Roman physician who lived in the second century CE. (common era = AD). In the early 1500s, Andreas Vesalius began dissecting human corpses and noticed that in many cases Galen had been mistaken. Vesalius promoted the idea that observation of the world itself was more accurate than accepting undocumented claims, even if the claims had been made by an extremely famous, respected person.
2. *Phenomena that can be studied. Only tangible phenomena and objects are studied,* such as heat, plants, minerals, and weather. We cannot see or feel magnetism or neutrons, but we can construct instruments that detect them reliably. In contrast, we do not see or feel ghosts, and no instrument has ever detected ghosts reliably: If ghosts do exist, they must be intangible and cannot be studied by the scientific method. Anything that cannot be observed cannot be studied.
3. *Constancy and universality. Physical forces that control the world are constant through time and are the same everywhere.* Water has always been and always will be composed of hydrogen and oxygen; gravity is the same now as it has been in the past. The world itself changes—mountains erode, rivers change course, plants evolve—but the forces remain the same. Experiments done at one time and place should give the same results if they are carefully repeated at a different time and place. Constancy and universality allow us to plan future experiments and predict what

the outcome should be: If we do the experiment and do not get the predicted outcome, it must be that our theory was incorrect, not that the fundamental forces of the world have suddenly changed. This prevents people from explaining things as miracles or the intervention of evil spirits. For example, if someone claims that a new drug cures a particular disease, we can check that by testing the same drug against that disease. If it does not work, the first person may have (1) made an innocent mistake, (2) tested the drug on people who would have gotten better anyway, or (3) been committing fraud; however, we do not have to worry that the difference in the two experiments is due to the fundamental laws of chemistry and physics having changed or that the first experiment's outcome was altered by benevolent spirits and the second by evil spirits.

4. *Basis. The fundamental basis of the scientific method is skepticism,* the principle of never being certain of a conclusion, of always being willing to consider new evidence. No matter how much evidence there is for or against a theory, it does no harm to keep a bit of doubt in our minds and to be willing to consider more evidence. For example, there is a tremendous amount of evidence supporting the theory that all plants are composed of cells, and there is no known evidence against it. All of our research, all of our teaching assumes that plants indeed are composed of cells, but the concept of skepticism requires that if new, contrary evidence is presented, we must be willing to change our minds. As a further example, consider people who have been convicted of crimes and then later—often years later—DNA-based evidence indicates that they are innocent: Skepticism is the willingness to consider new evidence.

Scientific studies take many forms, but basically, they begin with a series of observations, followed by a period of experimentation mixed with further observation and analysis. At some point, a hypothesis, or model, is constructed to account for the observations: A **hypothesis** (unlike a speculation) must make predictions that can be tested. For example, scientists in the Middle Ages observed that plants never occur in dark caves and grow poorly indoors where light is dim. They hypothesized that plants need light to grow. This can be formally stated as a pair of simple alternative hypotheses: (1) Plants need light to grow, and (2) plants do not need light to grow. The experimental testing may involve the comparison of several plants outdoors, some in light and others heavily shaded, or it may involve several plants indoors, some in the normal gloom and others illuminated by a window or a skylight. Such experiments give results consistent with hypothesis 1; hypothesis 2 would be rejected.

A hypothesis must be tested in various ways. It must be consistent with further observations and experiments, and it must be able to predict the results of future experiments: One of the greatest values of a hypothesis or theory is its power as a predictive model. If its predictions are accurate, they support the hypothesis; if its predictions are inaccurate, they prove that the hypothesis is incorrect. In this case, the hypothesis predicts that environments with little or no light will have few or no plants. Observations are consistent with these predictions. In a heavy forest, shade is dense at ground level, and few plants grow there (**FIGURE 1-8**). Similarly, as light penetrates the ocean, it is absorbed by water until at great depth all light has been absorbed; no plants or algae grow below that depth.

If a hypothesis continues to match observations, we have greater confidence that it is correct, and it may come to be called a **theory**. Occasionally, a hypothesis does not match an observation; that may mean either that the hypothesis must be altered somewhat or that the entire hypothesis has been wrong. For instance, plants such as Indian pipe or *Conopholis* (**FIGURE 1-9**) grow the same with or without light; they do not need light for growth. These are parasitic plants that obtain their energy by drawing nutrients from host plants. Thus, our hypothesis needs only minor modification: All plants except parasitic ones need sunlight for growth. It remains a reasonably accurate predictive model.

Note the four principles of the scientific method here. First, the hypothesis is based on observations and can be tested with experiments; we do not accept it simply because some famous scientist declared it to be true. Second, sunlight

(A) Courtesy of R. Fulginiti, University of Texas, Austin

(B) Courtesy of R. Fulginiti, University of Texas, Austin

FIGURE 1-8 **(A)** This aspen forest in Michigan does not have a dense canopy, but it intercepts so much light that few plants survive in the shade. The herb is the bracken fern *Pteridium aquilinum*. **(B)** Near the aspen forest is an open area with more light; herb growth, in this case a sedge, is much more abundant.

FIGURE 1-9 The yellowish flowers pushing out of the pine needle litter constitute almost the entire plant body of this parasitic plant, *Conopholis mexicana*. It is attached to the roots of nearby trees and draws nutrients from them. Like fungi, it cannot obtain its energy from sunlight, but so many other aspects of its anatomy and physiology are like those of ordinary plants that we have no difficulty in recognizing that this is a true plant, not a fungus.

and plant growth are tangible phenomena that we can either see directly or measure with instruments. Third, if we repeat the experiment anytime or anywhere, we expect to get the same results. Fourth, we interpret the evidence as supporting the hypothesis, but we keep an open mind and are willing to consider new data or a new hypothesis.

In former times, if a theory had sufficient support, it was referred to as a "law," such as the laws of thermodynamics or the law that for every action there is an equal and opposite reaction. Physicists occasionally still do this but biologists never use the term "law." Even though we have tens of thousands of observations that plants are composed of cells, there is no "law that all plants are composed of cells," instead we just treat this as a well-supported theory. No biologist expects that there will be a discovery that shows that plants are not actually made up of cells, but we simply do not ever use the term "law."

Many people attempt to discredit the theory of evolution by natural selection by saying that it is merely a theory of evolution, not a law of evolution; these people do not realize that their argument is nonsensical.

The concept of intelligent design has recently been proposed to explain many complex phenomena. Its fundamental concept is that many structures and metabolisms are too complicated to have resulted from evolution and natural selection. Instead, they must have been created by some sort of intelligent force or being. This may or may not be true, but this does not help us to analyze and understand the world; instead, it is used as an answer in itself that prevents further study. Photosynthesis is certainly complex, and it may have been designed by some intelligent being; however, believing that does not help us to understand photosynthesis at all, and it does not help us to plan future experiments. In contrast, the scientific method is a means through which we are discovering even the most subtle details of photosynthesis.

Areas Where the Scientific Method Is Inappropriate

Certain concepts exist for which the scientific method is inappropriate. We all believe that it is not right to wantonly kill each other, that racism and sexism are bad, and that things such as morality and ethics exist; however, both morality and ethics have no chemical composition, no mass, no electromagnetic spectrum—they are not tangible and thus cannot be studied by the scientific method. Science can study, measure, analyze, and describe the factors that cause people to kill each other or to be racist or sexist, and it can predict the outcome of these actions. Science, however, cannot say whether such actions are right or wrong, moral or immoral. Consider euthanasia: Many types of incurable cancer cause terrible pain and suffering in their final stages, which may last for months. We have drugs that can arrest breathing so that a person dies painlessly and peacefully. Science developed the drugs and can tell us the metabolic effects of using them, but it cannot tell us whether it is right to use them to help a person die and avoid pain. Biological advances have made us capable of surrogate motherhood, of detecting fetal birth defects early enough to allow a medically safe abortion, and of producing insecticides that protect crops but pollute the environment. These advances have made it more important than ever for us to have well-developed ethical philosophy for assessing the appropriateness of various actions.

Using Concepts to Understand Plants

The growth, reproduction, and death of plants—indeed, all aspects of their lives—are governed by a small number of basic principles. Each chapter in this text opens with a section called "Concepts," which discusses the principles most relevant to the topics in that particular chapter. Here in this chapter and at the beginning of your study of botany and plants, I want to introduce you briefly to some of these principles and to encourage you to use them as you read and think about plants. These concepts will make plant biology more easily understood—the numerous facts, figures, names, and data will be less overwhelming when you realize that they all fit into the patterns governed by a few fundamental concepts.

1. *Plant metabolism is based on the principles of chemistry and physics.* Weeds may seem to appear from nothing as if by magic; however, that is never true—they grow from seeds. All the principles you learn in your chemistry or physics classes are completely valid for plants.
2. *Plants must have a means of storing and using information.* After a seed germinates, it grows and develops into a plant, becoming larger and more complex; then it reproduces. The plant is taking in energy and chemical compounds and transforming them into the organic chemical compounds it uses to build more of itself. This requires a

complex, carefully controlled metabolism, and there must be a mechanism for storing and using the information that regulates that metabolism. As you may already know, genes are the primary means of storing this information.

3. *Plants reproduce, passing their genes and information on to their descendants.* Because an individual obtains its genes from its parents, the information it uses to control its metabolism is similar to the information its parent had used; thus, offspring and parents resemble each other. For example, a bean seed contains genes whose information guides the seed's metabolism into constructing a new bean plant, but a tomato seed grows into a tomato plant because it received different genes and information from its parents (**FIGURE 1-10**).
4. *Genes, and the information they contain, change.* As plants make copies of their genes during reproduction, accidental changes (mutations) occasionally occur, and this causes the affected gene and its information to change. This is quite rare, and most genes (and information) are passed unaltered from parents to offspring; however, as mutations occur and change a gene's information, they basically generate new information such that the plant that grows and develops under the control of the mutated gene may be slightly (or significantly) different from its parents. Thus, over time, a gradual evolution occurs in the genes, information, and biology of plants. Consequently, in a large population of many individuals of a species, some variation exists; the individuals are not identical (**FIGURE 1-11**).

FIGURE 1-10 This bean seed is developing into a bean plant, guided by genetic information it inherited from its parents.

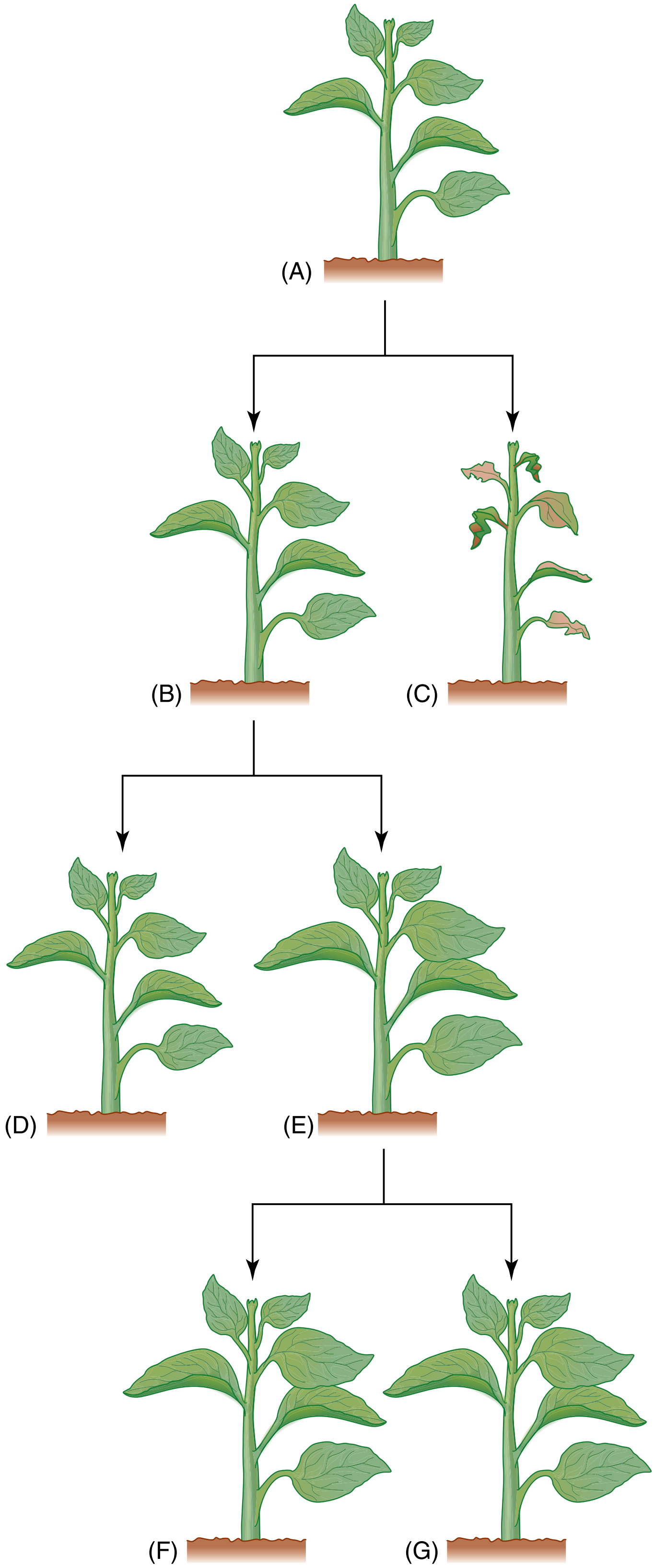

FIGURE 1-11 **(A)** A plant produces numerous offspring, many of which resemble it strongly **(B)**. Mutations may occur that cause, for instance, leaves to be malformed and poorly shaped for photosynthesis **(C)**; most or all these mutants die and do not reproduce. The normal plants continue to reproduce (B) and **(D)**, but another mutation may occur that causes the leaves to be larger and more efficient at photosynthesis **(E)**. These may grow and reproduce so well that they crowd out the original parental types, and the plant population finally contains only the type with large leaves **(F)** and **(G)** .

BOX 1-1 Plants and People, Including Students

Plants and people affect each other. The most obvious perhaps are the ways that people benefit from plants: They are the sources of our food, wood, paper, fibers, and medicines. It is difficult to excite students by listing the world production of wheat and lumber in metric tons, but just consider what your life would be like without chocolate, coffee, tea, sugar, vanilla, cinnamon, pepper, strawberries, mahogany, ebony, cotton, linen, roses, orchids, or the paper that examinations are written on. The oxygen we breathe comes entirely from plants. Plants affect each of us every day, not simply by keeping us alive but also by providing wonderful sights, textures, and fragrances that enrich our existence.

However, plants and people affect each other in ways that are not readily apparent in our day-to-day lives. Listed here are a few important topics you should be aware of. Think about their importance and how you—as an actual biological organism—interact with the other organisms on this planet.

Biotechnology is a set of laboratory techniques that allow us to alter plants and animals, giving them new traits and characteristics. Farmers have done this for thousands of years with controlled breeding of the best plants and animals (artificial selection), but biotechnology permits much more rapid, extensive alterations. We must now consider whether such manipulations are safe and worthwhile.

Global warming and *climate change* are caused by a buildup of carbon dioxide in our atmosphere caused by burning coal, oil, gas, and the trees of forests everywhere (not just tropical rain forests). Carbon dioxide traps heat, preventing Earth from radiating excess energy into space. Global warming is causing polar ice caps to melt, and climate change alters circulation of ocean currents and even the amount and pattern of rainfall. Preserving our forests and planting more trees might help stop and reverse global warming, but the possibility exists that global warming is preventing the occurrence of another ice age.

Desertification is the conversion of ordinary forest or grassland to desert. Accurate measurements are difficult, but it appears that deserts may be spreading as people cut shrubs and trees for firewood and allow goats to eat remaining vegetation. Once an area has been converted to desert, its soil is rapidly eroded, making recovery difficult. Something as simple as cheap solar cookers might prevent the Sahara desert from spreading farther across Africa.

Habitat loss results when an area is changed so much that a particular species can no longer survive in the area. Significant causes are the construction of highways, housing subdivisions, and shopping malls with enormous parking lots; these eliminate almost all species from an area, but habitats are also lost by logging, farming, mining, damming rivers, and spilling toxic chemicals. As habitat is lost, plants or animals must try to survive on the smaller remaining habitat. Once too little habitat is left, species usually become extinct.

Introduced exotics are organisms native to one part of the world but which have been brought to another part, where they thrive. Examples of introduced exotic animals are fire ants in the southern United States and zebra mussels in the Great Lakes region. Water hyacinth, purple loosestrife, and kudzu (a vine) were introduced to the United States and are now proliferating and reproducing so vigorously that they are crowding out many plants that normally grow here.

It is not realistic to believe that we humans will stop all activities that have negative impacts on our environment and on the other species with which we share this planet, but we can search for ways to minimize the harm we cause by recycling, conserving resources, and avoiding products that require pollution-causing manufacturing techniques.

(A)

(B)

FIGURE B1-1 Habitat loss is caused by many types of human activity. **(A)** This church parking lot covers acres of land previously used for grazing. Now it is used only 2 or 3 hours 1 day a week. Other than the few trees that were spared, it has no plants or animals, it prevents rain from soaking into the ground, and the asphalt leaches harmful chemicals into nearby creeks. No other business is nearby that could use this parking lot on weekdays or at night, which would at least provide additional benefit to offset the ecological damage it causes. **(B)** Even the construction of beautiful parks is habitat destruction.