Biology Success! Teaching Diverse Learners

A Resource Manual for Biology Educators

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Since coming to Landmark College in 1990, **Rich Grumbine**, associate professor of natural sciences, has tutored; taught biology, environmental science, and yoga; chaired the Natural Science Department; and served as the principal investigator for *Biology Success!*, a three-year project funded by the National Science Foundation's Research in Disabilities Education program. He received a master's degree from Antioch New England Graduate School in Keene, New Hampshire. He lives in Putney with his wife and 3-year-old son.

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INTRODUCTION

> "The challenge for both (post)secondary students with disabilities and institutions of (higher) education is to ensure that access really becomes opportunity."
>
> — Shaw & Scott 2003

THE AUTHORS of *Biology Success! Teaching Diverse Learners* accept the challenge, so clearly articulated by Shaw and Scott, to go beyond accommodating students with learning disabilities by providing real opportunities for academic success. The specific purpose of *Biology Success!* is to give introductory biology instructors at both the high school and college levels the ideas, tools, and inspiration for teaching to the great diversity of learners that walk into our collective classrooms each semester. While our perspective is mostly drawn from our work with students with learning disabilities, we believe that the practices and ideas presented in this book are widely applicable to all learners, with or without learning disabilities. This introduction presents the rationale and history of the project and an overview of the manual's contents.

Increasing Incidence of Students with Learning Disabilities in Higher Education

Over the last twenty-five years, the numbers of students with diagnosed disabilities participating in higher education has increased dramatically, from 2.3 percent in 1978 to 9.8 percent in 1998 (Henderson 1999). Two of the fastest growing categories of reported disabilities in recent years are students with learning disabilities and those with Attention Deficit Hyperactivity Disorder (ADHD). By 2000, 40 percent of freshmen with disabilities were classified with learning disabilities, compared to 16 percent in 1988 (Henderson 2001).

Why this rapid increase? Several factors are at play, but two major ones are most influential. The first is the trend toward higher levels of academic achievement for the majority of Americans. Well-paying factory jobs are increasingly scarce, and the disparity in earnings between those who complete just high school and those who graduate from college has continued to widen. In 1999 students who graduated from college earned between 58 percent and 92 percent more than those who graduated from high school. In 2000 more than fifteen million students enrolled in postsecondary education—approximately two out of three high school graduates (U.S. Department of Education 2000).

A second contributing factor in increased numbers of students with disabilities in higher education is legislation such as the Rehabilitation Act of 1973 and the Americans with Disabilities Act of

1990 which prohibit discrimination as a matter of civil rights. While these laws guarantee equal access to public institutions such as colleges and universities, students with disabilities still "face significant barriers to achieving their goals" (U.S. Department of Education 2002). College participation and graduation for students with disabilities still does not match that of their nondisabled peers. For example, students with disabilities "who enroll in a two-year program with the intention of transferring to a four-year school do not, and students with disabilities are less likely to persist in earning a postsecondary degree or credential than peers without disabilities." (U.S. Department of Education 2000).

Universal Design

Until recently, services for students with disabilities at the postsecondary level have focused on accommodations, usually provided through a campus office for students with disabilities (OSD). In this model, students with disabilities disclose their condition and provide documentation to support it, while the OSD determines appropriate accommodations, such as extended time on tests or priority registration, and negotiates with faculty to ensure these are provided. Under this approach, students with disabilities are somewhat stigmatized by virtue of being singled out for "alternative treatment."

However, recently there has been a growing interest in more systemic approaches to serving students with disabilities, one that also takes into account the growing numbers of students in other categories at risk for academic struggle: minority students, older students, first-generation college students, students whose first language isn't English. Foremost among these approaches is the movement toward Universal Design.

The Universal Design movement had its origins in providing physical access for individuals with mobility and sensory impairments, not by retrofitting with ramps and out-of-the-way elevators, but by integrating improved access into the overall design, enhancing both the aesthetic and practical aspects of the environment. Educators at the Universities of Massachusetts, Connecticut, and elsewhere have adapted this approach for academic environments: instead of providing accommodations that equalize access for a few specifically designated individuals with "invisible" handicaps such as learning disabilities, they advocate approaching curriculum design and instructional delivery with the needs of diverse kinds of learners in mind.

Shaw & Scott's article for the Fall 2003 issue of the *Journal of Postsecondary Education and Disability* summarizes the Universal Design movement and their University of Connecticut version of the nine principles. An approach like this promotes systemic change rather than focusing on individual accommodation and brings a welcome emphasis on good pedagogy to the realm of postsecondary academics. Furthermore, it empowers faculty to be the engines of change, recognizing their unique role in direct educational reform. It is fair to say that the *Biology Success!* manual grows out of the Universal Design approach to education, yet Landmark College's instructional practices, which form the basis of the manual, antedate this approach and also make some unique contributions.

Landmark College

Landmark College was founded in 1985 as the nation's and, to the best of our knowledge, the world's first postsecondary institution exclusively designed to meet the academic needs of high-achieving students with learning disabilities and ADHD. The college grew out of a successful program for similar high school students, the Landmark Schools in Beverly, Massachusetts. Both institutions were the brainchild of a brilliant—and extremely dyslexic—visionary educator, Dr. Charles

Drake, who developed many of the effective educational approaches practiced at the schools and college.

Dr. Drake believed in direct instruction rather than bypass techniques: his programs focused on improving students' ability to read, write, take notes, and stay organized instead of using books on tape, scribes, or note takers as in other programs. He held the highest expectations for students but realized that specialized techniques, often multisensory, were key to teaching students who "learned differently." These techniques often capitalized on students' strengths and talents and fostered "metacognition"—the ability to understand one's unique learning profile and to develop and practice strategies appropriate to it. Teachers also need to be well versed in understanding student profiles so they can design courses that are diagnostic and prescriptive, responding to where students are in their academic knowledge and skills when they arrive in class. The six educational principles and four widely beneficial practices that are described beginning on **page 2** have been the foundation of the academic program at both the Landmark Schools and Landmark College, and thus they form the basis for this *Biology Success!* manual.

A Brief Overview of Learning Disabilities

What do we mean when we use the terms *learning disabilities* and *ADHD*? The term "learning disability" goes back only to 1962, when psychologist Samuel Kirk and a group of parents coined it to describe students who seemed bright and capable in most regards but who failed to make expected academic gains in specific areas such as reading or math (Kirk 1963). Their definition evolved over the years in response to research and changes in educational policy, to the most recent definition from the United States Department of Education's 2002 Common Ground Round Table:

> The term "learning disability" refers to a class of specific disorders. They are due to cognitive deficits intrinsic to the individual and are often unexpected in relation to other cognitive abilities. Such disorders result in performance deficits in spite of quality instruction and predict anomalies in the development of adaptive functions having consequences across the lifespan. (Dickman 2003)

In current practice, only students who show a significant discrepancy between their potential (as measured by IQ-type tests) and their academic performance meet definitional standards to qualify for special education services in most states; however, a great weight of evidence from research, and a realization that waiting for that discrepancy to appear often means enduring three to four years of school failure, has led to the questioning of that discrepancy formula, and we expect it to be replaced by other means of (earlier) identification over the next few years (Dickman 2002).

The most common form of learning disability is reading disability. Sometimes this is called dyslexia; unfortunately, terminology, like diagnostic criteria, can vary from state to state or region to region. Students with reading disability obviously face a struggle in learning to read accurately and fluently. Generally, this begins as difficulty with decoding (recognizing and pronouncing words), but trouble with comprehension often follows because the decoding is slow and laborious, and students' vocabulary becomes impoverished because of their reluctance to read. Most dyslexic students also show poor spelling and struggle with academic writing. Sometimes oral language is also affected; it may take extra time to process what they are hearing and to formulate a coherent, elaborated response. On the other hand, many dyslexic students are fluent and articulate with oral language, and the disparity between their verbal gifts and their reading and writing skill becomes a cause for great frustration, or for skepticism on the part of teachers and parents that the students are "applying themselves" to their work.

A growing diagnostic category that is not, strictly speaking, a learning disability but nevertheless adversely affects academic performance is that of the attention disorders, variously called ADD (Attention Deficit Disorder), ADHD, or AD/HD (Attention Deficit–Hyperactivity Disorder). Unlike dyslexia, which is diagnosed by educational specialists through a series of performance tests and by looking at academic achievement, ADHD is actually a medical condition, diagnosed most often by a psychiatrist or pediatrician through a series of focused interviews and behavioral checklists.

The core symptoms of ADHD are considered to be distractibility, impulsivity, and hyperactivity. However, this is a little misleading, as a significant percentage of individuals with the disorder don't exhibit hyperactivity at all, but are more prone to inattentiveness. The secondary characteristics include mental effort depletion, performance inconsistency, and difficulty with executive functions, which involves the ability to set and hold goals, plan strategies for meeting goals, and monitor behavior. Students with executive function difficulty typically have trouble keeping appointments, meeting deadlines, and balancing personal and academic demands, and they often fail to complete assignments despite obvious command of necessary skills. They appear to be disorganized in keeping track of materials as well as in managing time.

As with dyslexic students, when students with ADHD are undiagnosed, those around them tend to attribute their difficulties to laziness or lack of motivation, rather than to recognize the origins of these difficulties as an organic condition that is not completely under voluntary control. Often, medication (originally stimulants and now also alternative forms) is part of the treatment program for individuals with ADHD. Medication helps regulate the faulty levels of neurotransmitter activity that are associated with this diagnosis. One important note: dyslexia and ADHD often seem to co-occur. At Landmark College approximately 60 percent of students have this dual diagnosis.

Smaller numbers of students may fall into some lesser-known categories of learning disability; dyscalculia, nonverbal LD, and Asperger's syndrome share some characteristics. Students with dyscalculia experience their major difficulties in the area of math, in their ability both to understand and apply number concepts and to remember basic math facts (like the multiplication table) and accurately perform arithmetical calculations. Sometimes these issues stem primarily from problems understanding the specialized, often sequential, symbolic language of math. In other cases, the main difficulty seems to be related to difficulty understanding and interpreting visual-spatial information, a key component of geometry, graphing, and other aspects of math.

The relatively new categories of nonverbal LD and Asperger's syndrome are still developing, and experts disagree somewhat on the precise definitions and cluster of characteristics. They share a difficulty in processing visual-spatial information, such as described in dyscalculia, and often students with these diagnoses struggle with math. However, in addition, a defining characteristic relates to great difficulty in interpreting the nonverbal components of everyday communication, sometimes referred to as "body language." Individuals with these diagnoses fail to notice or misinterpret aspects of language such as tone of voice, facial expression, and stance. As a result, they struggle with the social aspects of school and experience difficulty sustaining relationships with peers. They are uncomfortable with "small talk" and tend to limit their conversations to a narrow choice of favorite topics, and they misread nonverbal cues, failing to notice how people are responding to them.

Some experts distinguish nonverbal LD from Asperger's syndrome (sometimes called "high-functioning autism") by looking at the quality of emotional response. According to this classification, Asperger's syndrome also entails great difficulty in understanding and relating to the emotional component of human interaction. Like Mr. Spock on the spaceship *Enterprise*, individuals with Asperger's syndrome can learn to analyze human emotional response but don't spontaneously experience it for themselves. This may seem unrelated to academic success or failure—indeed, often individuals with Asperger's syndrome seem to be brilliant in their chosen areas of intellectual pursuit—but when we consider how much of school-based learning involves the "social construction of meaning," the fact that these individuals don't easily fit in and appear socially inept tends to have a negative impact on their overall academic functioning.

Some experts in the field of learning disabilities—notably Dr. Mel Levine, founder of All Kinds of Minds and the "Schools Attuned" programs—discredit the pigeon-holing of individuals under rigid diagnostic taxonomies, and argue instead for a phenomenological approach which evaluates individuals in terms of their strengths and specific challenges in the neurodevelopmental areas that form the basis for learning. Levine's "Interactive Neurodevelopmental Paradigm" takes a dynamic view of how biology and environment interact over time to create individual patterns of functioning (Levine et al. 1993). It analyzes individual student profiles in the areas of attention, memory, language, neuromotor skills, social function, sequencing temporal and spatial information, and higher-order cognition; helps individuals to understand the unique ways their brains function; and offers hope as well as specific recommendations for support and strategy use to overcome difficulties by capitalizing on areas of strength and competence. This approach has been critical in shaping Landmark College's academic programs and approaches since the early 1990s, when Dr. Levine made several visits to the Landmark campus.

A Note on Terminology

The *Biology Success!* project falls under NSF's Research in Disabilities Education (RDE) program, so we have been using the term "learning disabilities" to identify the kinds of students for whom this manual was created. There is, however, a growing movement in the disabilities field to replace the term "learning disability" with "learning difference." There is also controversy among teachers, students, and researchers about what to call the well-documented phenomenon of students who seem generally bright and capable but who struggle with specific aspects of academic performance such as reading, writing, or mathematics.

There are strong arguments for both terms. First of all, "disability" is actually a legal term that defines who is eligible for services and accommodations under the several federal laws that govern treatment of individuals with disabilities. So anyone who currently plans to take advantage of these legal rights must be willing to accept the label of "learning disability." Those who favor the term "learning disability" also argue that the kinds of difficulties experienced by these designated individuals go well beyond the ordinary differences among learners, and that to use the term "learning difference" belittles the grave obstacles they face, especially in academic settings.

On the other hand, proponents of the term "learning difference" point out that the term "disability" carries a real stigma and seems to imply that those affected are incapable of learning, when in fact, with appropriate teaching methods, they can become very successful students and lifelong learners. Most students at Landmark College prefer to refer to themselves as persons who learn differently, rather than as individuals with a learning disability. It fosters self-esteem and increases their confidence as learners. There's growing support for the term among professionals, too. Charles Schwab, the well-known "dyslexic CEO," who not only advises people on how to manage their money but also sponsors two excellent Web-based resources (www.ldonline.org and www.schwablearning.org), is a strong advocate for the term "learning difference," and venerable institutions such as the International Dyslexia Association are moving toward adopting this term.

We are likely to see both terms persist over the next three to five years, and perhaps a new term altogether will emerge; eventually those who carry the label will have enough political savvy and power to decide what that label should be.

An Overview of the Structure of *Biology Success! Teaching Diverse Learners*

The *Biology Success!* manual has two primary subdivisions: a primer on the key pedagogical practices that should inform the teaching and learning of biology, and a sampling of introductory biology activities that exemplify the principles and practices described in the first section.

In the first subdivision, we begin by elucidating the six educational principles and subprinciples that form the backbone of Landmark College's teaching philosophy. This is followed by a description of what we call "widely beneficial practices" for structuring lessons to meet the needs of diverse learners. We continue with short pieces that illustrate ideas and techniques for starting courses, teaching study skills that support the learning of biology, varying how instruction can be delivered, assessing the progress of students, facilitating learning through the laboratory experience, and using online biology learning resources effectively.

The second subdivision consists of nineteen sample activities in the core introductory biology topic areas of cell biology, evolution, genetics, and ecology. The intention of presenting these activities is not to show an ideal introductory biology curriculum per se, but rather to demonstrate the application of the educational principles and widely beneficial practices described earlier in the book. Many of the activities have a student handout that is ready to copy and distribute, designed to make the activity easy to use with students.

We have also included a CD on the inside front cover that offers three additional resources: video clips of two sample activities ("Cell Cycle Role Play" and "Mendelian Genetics") from a *Biology Success!* teacher workshop; an interactive Web-based activity called "The Cell Tour"; and student handouts in both Microsoft Word and rich text format.

How to Get the Most Out of This Book

Our professional lives are busy, and although we would love to think that all readers will examine this resource carefully from cover to cover, we recognize that this is not likely. Depending on your learning and teaching temperament and needs, you may be attracted to the activities in the last section, where you can consider concrete ways to teach the content of introductory biology. Or you may be attracted to the pedagogical presentation of the first section of this book and immediately begin by exploring the educational principles that underpin the entire book. Or perhaps you have a specific need or interest to learn about a specific technique, such as rubrics, and decide to begin your exploration by turning to the pages on assessment. All of these approaches are valid, and we hope the design and content of this book can readily facilitate your productive engagement no matter where you start. We view *Biology Success! Teaching Diverse Learners* as a vast toolkit for best teaching practices; use the tool that best fits your professional needs.

That said, we do believe that grounding our biology teaching in some conscious pedagogy has a high value. So please afford yourself the time to read the introductory section on the educational principles so you can understand more deeply all that follows.

We hope you consider this book a long-term investment and resource to come back to again and again. And while it is overwhelming to consider a wholesale transformation of your teaching practices, making incremental change is a more realistic expectation. We can't change our practices (or our students) overnight. Key in on one particular area for your development (assessment, study skills, multimodal teaching, etc.) and start from there. Over time, you will slowly modify your teaching practices to better suit the needs of all students in your biology classroom and provide real and lasting opportunities for success.

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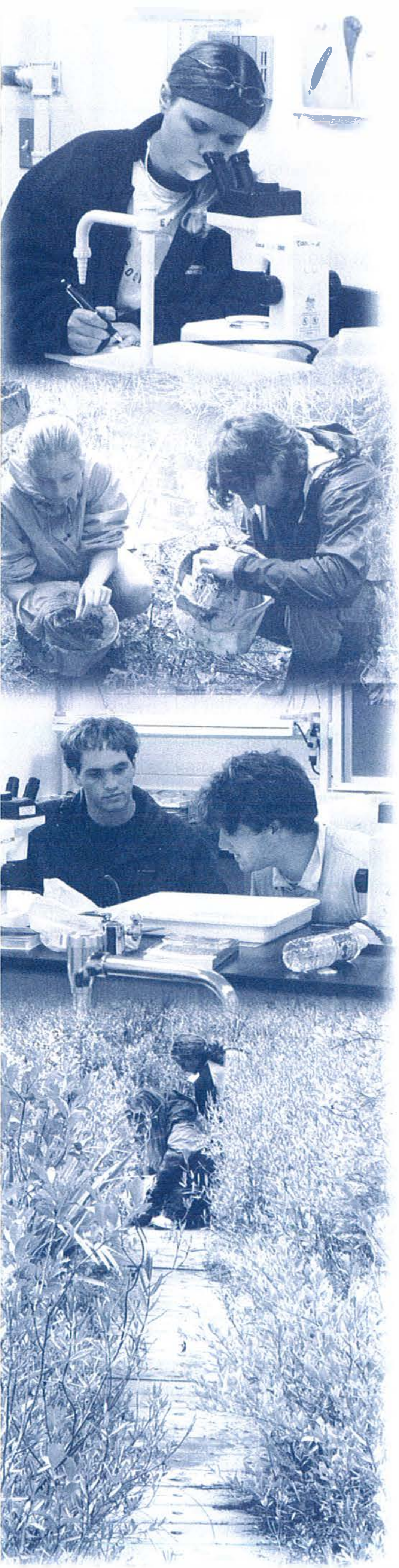

1

SIX GUIDING EDUCATIONAL PRINCIPLES

THIS BOOK demonstrates how to adapt the curriculum of introductory biology courses to serve both traditional students and those with learning disabilities in the kinds of heterogeneous classes typical of high schools and colleges. Landmark College's Six Guiding Educational Principles are the cornerstone of the college's successful academic programs and the foundation for the ideas, techniques, and activities presented in *Biology Success! Teaching Diverse Learners.* While these principles were not invented by nor are they exclusive to Landmark College, the way Landmark faculty consciously and systematically incorporate these principles into curriculum design and classroom practice may be unique.

Throughout nearly twenty years of effective classroom practice, Landmark College faculty have been guided by a set of educational principles that predate the founding of the college in 1985, and recall the college's origins as an offshoot of the Landmark Schools in Beverly, Massachusetts. Both the college and the schools were founded by Dr. Charles Drake, a brilliant educational visionary and profoundly dyslexic individual, who developed many of the teaching techniques that are practiced every day in Landmark College classrooms.

These principles, which are founded on a deep understanding of the learning process, can improve instruction for any student. Still, it is important to remember that while these principles may be beneficial to all students, they are *essential* for students with learning disabilities.

processes. Teachers observe students' progress by evaluating and recording their performance in everyday class activities such as homework completion, contributions to discussions and small-group work, in-class exercises, and lab activities. When individual students fail to master important ideas, teachers can refer them to office hours, peer tutors, or support centers for extra help; but when groups of students fail to grasp concepts, teachers will need to rethink lesson plans and devise alternative ways to present information, rather than just forging ahead to the next topic.

More on **using a diagnostic-prescriptive approach** can be found on the following pages:

- **Learning Style Assessment,** page 37
- **Student Background Knowledge,** page 42
- **Multimodal Teaching,** page 81
- **Graphic Organizers,** page 84
- **Effective Review,** page 119
- **An Overview of Assessment,** page 123

Principle 2: Provide explicit instruction in skills and strategies

2a. Teach strategies and procedures explicitly

One of the most distinctive features of a Landmark education is its emphasis on direct teaching of skills that students are often assumed to possess, such as note taking, text reading, and report writing. At Landmark College, students actually learn how to learn; the program specializes in uncovering what is sometimes referred to as "the hidden curriculum" of language and study skills that underpins success in academic settings at the secondary and postsecondary levels (Oliver et al. 2000).

In addition to explicit teaching of language-based skills that involve classroom listening, speaking, reading, and writing at appropriate levels, Landmark faculty have discovered the importance of directly teaching executive-function skills that are critical to academic success: setting goals, selecting effective strategies, monitoring progress, and critical self-reflection. These skills are introduced in a course called Reading and Study Skills that all students take in their first semester at the college, and they are continually retaught, refined, and monitored in all classrooms. Thus, in a science class, teachers incorporate the following kinds of skills instruction and expectations into their content-based curriculum:

- Reading science text books
- Maintaining a course-specific master notebook
- Learning and retaining vocabulary
- Writing lab reports
- Concept mapping
- Taking tests

2b. Break tasks and skills into subskills, staged procedures, and other processes

This approach is sometimes called "micro-uniting." Although it may seem obvious to teachers how to break down a research project into the stages of (1) determining a topic; (2) gathering information; (3) constructing an outline; (4) writing a draft; and (5) revising to produce a final draft, many students with learning disabilities lack the executive-function or language skills to divide the project into discrete steps that can be tackled individually without getting overwhelmed by its immensity or lost in the welter of details.

Therefore, effective teachers will guide students through the process of breaking a task into its component stages, and will support them by collecting work at each stage and returning it with feedback and suggestions about the effectiveness of the process as well as the quality of the product. This instance) that are being tested but their competencies as well. (**See also Principle 4**)

3c. Set clear expectations and support students in meeting them

All students benefit from clear expectations, but students with learning disabilities in particular may need to have expectations spelled out in ways that teachers take for granted, and repeated many times in different formats. For instance, if you expect lab reports to be typed and of a certain length, state those expectations explicitly in writing and remind students often. Ask students with learning disabilities to reverbalize assignments and state what materials they will need to complete them; or ask them to check their assignment books to make sure they have written down the assignments accurately. Give students firm assignment and project deadlines, visually represented on a calendar, and review these deadlines in class frequently. Provide templates and models for projects, so that students know what a lab report should look like, as well as rubrics that clarify exactly what the differences are between an A-worthy project and one that earns a B or a C.

More on **providing a student-centered classroom** can be found on the following pages:

- **Course Organization,** page 29
- **Learning Style Assessment,** page 37
- **Student Background Knowledge,** page 42
- **Inductive and Deductive Teaching Approaches,** page 102
- **Discussion,** page 107
- **Writing Models,** page 113
- **Rubrics,** page 127
- **Testing,** page 140
- **The Biology Laboratory,** page 157

Principle 4: Address diversity of learning styles

4a. Create a strength-based context

Howard Gardner's *Frames of Mind* (1983) delineates a view of intelligence that asserts there is not just one way to be "smart," and that cultivation of a variety of intelligences is critical to the continued well-being of the human species. In addition to the kinds of intelligence that are traditionally valued and nurtured in schools (mathematical-logical and linguistic), Gardner also argues for the importance of visual-spatial, tactile-kinesthetic, musical, interpersonal, intrapersonal, and naturalist intelligences.

This view of variable forms of intelligence provides a framework for regarding students with learning disabilities in a new light. It allows us to see a dyslexic individual not just as someone who is disabled in regard to reading, but as someone who may possess high levels of visual-spatial or musical intelligence but relatively lower levels of linguistic intelligence. Acknowledging that all individuals vary in their relative strengths and weaknesses across the spectrum of multiple intelligences lets us discard the notion of students with learning disabilities as individuals who are "broken" and therefore need to be "fixed" so they can be like everyone else. It also encourages us to seek out students' areas of strengths and use them as leverage in addressing areas of weakness (Levine 1994).

4b. Incorporate visual-spatial, kinesthetic, and tactile modalities

Landmark College instructors, as well as others in the field of learning disabilities, have observed that "students with learning disabilities often have pronounced strengths in processing information using alternative pathways, such as a visual, tactile, or kinesthetic approach, rather than relying on strictly auditory processing, which is often their weakest

4e. *Value alternative modes of intelligence*

We recommend that diversity of learning styles be addressed openly and in a friendly context from the first day of class. Teachers who assess students' learning styles and prior knowledge, engage students in discussing how the students learn best, and explicitly talk about how they shape their courses to the individual needs of students are modeling that they value diversity in learning. Looking at exemplary scientists who apparently had learning disabilities, such as Einstein, Edison, Maxwell, and Faraday, helps students understand that thinking differently can lead to excellence and innovation, not just to academic failure (West 1991). This in turn encourages students to value their own approach to learning and to develop strategies that capitalize on their strengths.

More on **addressing a diversity of learning styles** can be found on the following pages:

- **Learning Style Assessment,** page 37
- **Assistive Technology,** page 75
- **Multimodal Teaching,** page 81
- **Graphic Organizers,** page 84
- **Concept Mapping,** page 90
- **Effective Review,** page1 19
- **Testing,** page 140
- **Poster Presentations,** page 151

Principle 5: Base instruction and assessment on clear objectives

5a. *Identify agendas, learning goals, means, and standards for assessment*

It's self-evident that teachers should supply students with a course syllabus that lists texts, readings, and important assignment due dates. But students with learning disabilities sometimes have difficulties relating the minutiae of a course to its overarching themes and goals. They might also have trouble breaking down the big picture of what's expected into manageable parts. We find that these students benefit from an augmented syllabus that clearly defines goals and activities along a semester timeline or calendar, and that explains in detail the criteria by which their work and content mastery will be assessed. This more detailed approach should be applied at the start of a semester, when introducing new units, and at the beginning of each class when a preview of the daily agenda will help students focus on upcoming activities. It's not enough just to hand out the agendas, syllabi, or rubrics to students and assume they will accurately interpret the information on their own. Teachers need to discuss the content, invite questions from students, and cue them to reverbalize some of the information in their own words.

5b. *Link agendas and goals to learning objectives*

Students perform better when they have a clear purpose in mind. When teachers explain the "why" of daily, weekly, or semester-long readings and activities, explicitly linking them to the course objectives stated at the start of the course, students are more motivated to invest effort in their work. For example, when previewing a daily agenda or weekly plan, ask students to pull out their syllabus and refer to the course objectives. Explicitly discuss which objectives will be addressed by the activities they are about to undertake. We recommend that teachers introduce most activities with a brief discussion of both "Why are we doing this?"—linking to learning objectives—and "Why are we doing it *this way*?"—linking to learning styles and encouraging students to think reflectively and be strategic. **(See also Principle 6)** demic failure, these students stop expecting things to make sense, fall back on ineffective learning techniques such as rote memorization, and lose their confidence and ability to be self-reliant in learning situations. One of Landmark College's key principles entails fostering students' active learning and independence through developing metacognition. Literally, this means "thinking about thinking." In practice, it means helping students understand how their learning profiles (the sum of their academic strengths and challenges) relate to the learning process. Ideally, students with highly developed metacognitive skills can understand and articulate their learning profiles, and select and implement effective strategies.

Metacognition rarely develops spontaneously. Rather, teachers need to support its development by building reflective activities throughout the curriculum, from initial discussions about learning styles in the opening days of a course to components of final projects or exams that ask students to think about *what* they learned and *how* they learned it. Students may be asked to keep weekly "learning journals" where they record their observations and questions about their learning processes in an unstructured format. On long-range projects, teachers will want to assign preplanning worksheets, midprocess reflections, and summary reflections, where students respond to questions such as these:

- "What do I think will be the hardest part of this project?"
- "Where can I go for assistance if I get stuck?"
- "What strategies have I learned that can assist me with this project?"
- "How would I grade myself on this project for (a) mastery of content, (b) efficient completion of the process?"
- "What have I learned from this project that may be useful next time?"

REFLECTION QUESTIONS FOR DEVELOPING STUDENT METACOGNITION

The following are examples of questions that instructors can share with students to build their metacognitive skills.

- What learning strategies did you use to understand the course material in this lesson or unit?
- How well did this activity or lesson suit your learning style?
- What, if any, were the most difficult aspects of learning in this lesson, class, or unit?
- What would you do differently next time when asked to complete a similar assignment?
- What aspects of this assignment, lesson, or unit most contributed to your learning?
- How can this lesson, assignment, or unit be improved upon to make it a better learning experience?
- What learning strengths were revealed in the process of completing this assignment?
- What learning weaknesses were revealed in the process of completing this assignment?

We have included reflective/metacognitive questions in each of the activities presented in this book, starting in Section 6 **on page 191**.

6b. Be explicit about how learning takes place and breaks down

When teachers share their thinking about why they have created lessons and activities in a certain order and fashion, students can expand their awareness of how learning takes place. For instance, when assessing students' prior knowledge about a topic, teachers can provide the rationale that prior knowledge needs to be activated in order for new learning to take place. When

2 WIDELY BENEFICIAL PRACTICES

IN ADDITION to the Six Guiding Educational Principles, there are a number of classroom practices for structuring lessons that will greatly support students with learning disabilities while benefiting all students. These are sometimes referred to as Universal Design practices, using an analogy to an architectural concept: when environmental modifications for individuals with disabilities (such as ramps for individuals with mobility impairments) are part of a building's intrinsic design, they can benefit everyone, and are less expensive and more attractive than when they are added on as an afterthought. The concept of Universal Design applied to educational practices currently enjoys widespread popularity, and a number of institutions employ different versions of Universal Design principles (University of Massachusetts, University of Connecticut, Center for Applied Special Technology [CAST], and University of South Dakota). We'll refer to our version as *Widely Beneficial Practices.*

Most of the material in this section comes from "Making College Classrooms Accessible to Students with (and without) Learning Disabilities," by Christina Herbert, in the Landmark College guide *Promoting Academic Success for Students with Learning Disabilities* (Strothman 2001).

Advance Organizers

The term *advance organizer* was coined by cognitive psychologist David Ausubel in the 1950s, and the concept has been widely practiced and studied since then (Newell 1984). According to Ausubel, Novak, and Hanesian (1978), advance organizers may be defined as "material presented at a higher level of abstraction, generality, and inclusiveness than the material to be learned." Some claim that an advance organizer is "not an overview . . . but an 'umbrella' for new material to be learned" (Douglas, Maineville, and Smith 1997).

Good teachers use advance organizers to help students connect what they already know to new information they are about to learn. Advance organizers have been used in many settings, from elementary school through university, and they can take many forms.

At Landmark College, they have the form of specific, concrete steps taken to *organize* and *motivate* students *in advance*. Usually, they give students a "map" of an upcoming unit, lesson, or activity and a sense of direction. They focus on both the content to be learned and the process by which it will be learned.

Several distinct kinds of tools—agendas, course maps, and activators—are used to improve students' thematic awareness and to clarify instructional objectives, which are often an unintentionally hidden part of the curriculum.

Agendas and Course Maps

The *agenda* is a calendar of the steps the class will take and the assignments the students will receive. Agendas need to be presented both visually and verbally. They help students prepare to focus on the upcoming material and to pace themselves through the activities for the day or the unit.

At the unit level, agendas function as course "maps" and include the following:

- Unit title
- Approximate unit length
- Key learning objectives
- Due dates and rationales for important assignments
- Test dates and test formats
- Vocabulary list

This information should be conveyed in a simple, visually accessible format. **See pages 18–25** for four examples of course maps in the areas of ecology, evolution, cell biology, and genetics.

At the level of the daily lesson, Landmark College's use of agendas entails discussing the day's activities and goals with support from a visual representation (in words or graphics) on the board or on a transparency. **See Figure 3.1 on page 31** for an example of a daily agenda.

Activators

Activators are a kind of advance organizer designed to activate a personal connection to the lesson and to motivate students to want to learn more. Activators also check what students already know about a topic. We know from research into schema theory (Lazear 1993) that the brain processes new information by associating and linking it with what is already known. For students with learning disabilities, there may be significant background knowledge deficits caused by their difficulties with reading or processing information. The use of activities designed to consciously activate a connection to the new material helps these students make connections in a way that they might not do independently. Activators are also good diagnostic tools for teachers to use in assessing what students already know or understand about a given topic. And they provide a reference point for progress, revealing how much more students understand at the end of the unit of study. **See** "Student Background Knowledge" on **page 42** for more information on basing instruction on student preconceptions.

Some options for activators are the following:

- A poster that shows a variety of life forms or cycles before students are introduced to a particular example
- A quotation that gets at the essence of content
- Photographs or paintings of a historic event related to a scientific concept or invention

A teacher may ask students to respond in a variety of ways, such as brainstorming or freewriting their ideas. Alternatively, teachers may ask students to draw a picture or diagram of what they understand about the given topic. It is important for the teacher to allow time in class for students to explore their connections to a topic in advance of a lesson.

Connectors

Connectors refer to those activities designed by faculty to help students identify connections between previously introduced course concepts and new ones. Research on characteristics of expert learners (National Research Council 1999) points to experts' superior ability to make connections with old material, and their flexibility in seeing how the new relates to the old. Students with learning disabilities may be characterized by difficulties in making these connections. Saphier and Gower (1997) liken this process to presenting students with a metaphor of the course as a chain of concepts, and developing their ability to see how the new links fit onto the whole of the chain. Connectors are closely related to activators; the chief distinction is that connectors are used throughout the lesson to link new to old knowledge, while activators are used before introducing new information to stimulate students' access to what they already know.

Connectors are especially useful in helping students grasp abstract theories or processes by helping them connect these theories to something they already know. There are several relatively direct and simple ways that teachers can use connectors in the classroom. Graphic organizers such as Venn diagrams, matrices, and flow charts help students see how concepts are connected. Analogies help students understand a process by comparing it to something already familiar (How is learning like growing a garden? How is this approach to an experiment similar to the previous one we used in class?). Each of the nineteen activities beginning **on page 193** in Section 6 contains an activator or connector idea that is typically the starting point for the lesson.

Summarizers

Summarizers are activities that allow frequent opportunities for students to summarize, review, and synthesize class material. When teachers break lessons into smaller chunks and allow for incremental review, students are more likely to retain information. Summarizers also serve teachers with ongoing feedback about the quality of student synthesis of information. They thus provide an opportunity to address misconceptions far in advance of exams, when it's too late for students to benefit in any way. Summarizers serve as the "glue" for cementing concepts, and they help students determine what is salient—specifically, how their conceptualization of key information does or doesn't coincide with the teacher's intent.

One way for teachers to integrate summarizers into the classroom is to develop a vocabulary that cues students to the importance of main ideas or key concepts. Throughout a lesson, a teacher can return to this key phrase, asking questions like "So, what's the point of all this?" "What do you take away from the discussion?" "How does this relate to the main idea we're studying today?" Allowing students time to identify and sum up their understanding is critical. In addition, teachers need to ensure that their summarizers do not rely just on discussion, but that they allow students to write or draw their understandings or to discuss them with peers.

Some options for summarizers include the following:

- Brainstorm the key points from the day's lesson; write them on the board
- Have students identify the one question or concept they are taking away from the day's lesson
- Identify the main point they think was made in the lesson (or the three main points, two questions, and one way the lesson relates to a previous lesson in the course)
- Write a five-minute summary of the most important points of today's class
- Create a concept map that shows the relationship among the points of the day's lesson
- Generate three types of questions around the day's lesson: clarification, critical thinking, and test questions

Another helpful way to integrate summarizers is to have students use a two-column note-taking approach and revise their notes in class. It enhances salient memory storage when teachers allow time at the end of any given class for students to process what they've learned. Summarizers are incorporated into all of the activities presented in Sections 6 through 10, usually in the Follow-up Discussion Questions section of the activity.

Giving Clear Directions

Students with learning disabilities are often at a disadvantage when it comes to following procedures and directions in the classroom. Their difficulties with language processing or distractibility may mean that they miss oral cues or directions and are therefore feeling lost as the students around them proceed with assurance into a new part of the lesson. Those students with executive-functioning difficulties, i.e., difficulty planning, prioritizing, and following through on work, may struggle in particular with longer-term assignments that are unclear. The guiding principles for creating good directions in class are to make them concise, visual, and organized.

Teachers are likely to communicate information well if they follow the essential concepts that good directions are clearly stated *and* written in a clear and meaningful way, using a step-by-step list and avoiding too much abbreviation, assumed language, or excessive description. **See page 252** for an example of a student assignment packet designed to convey clear directions.

On page 16, we have also provided a Widely Beneficial Lesson Plan Design template. It is meant to be used as a tool to prepare a lesson that incorporates many of the Widely Beneficial Practices described in this section.

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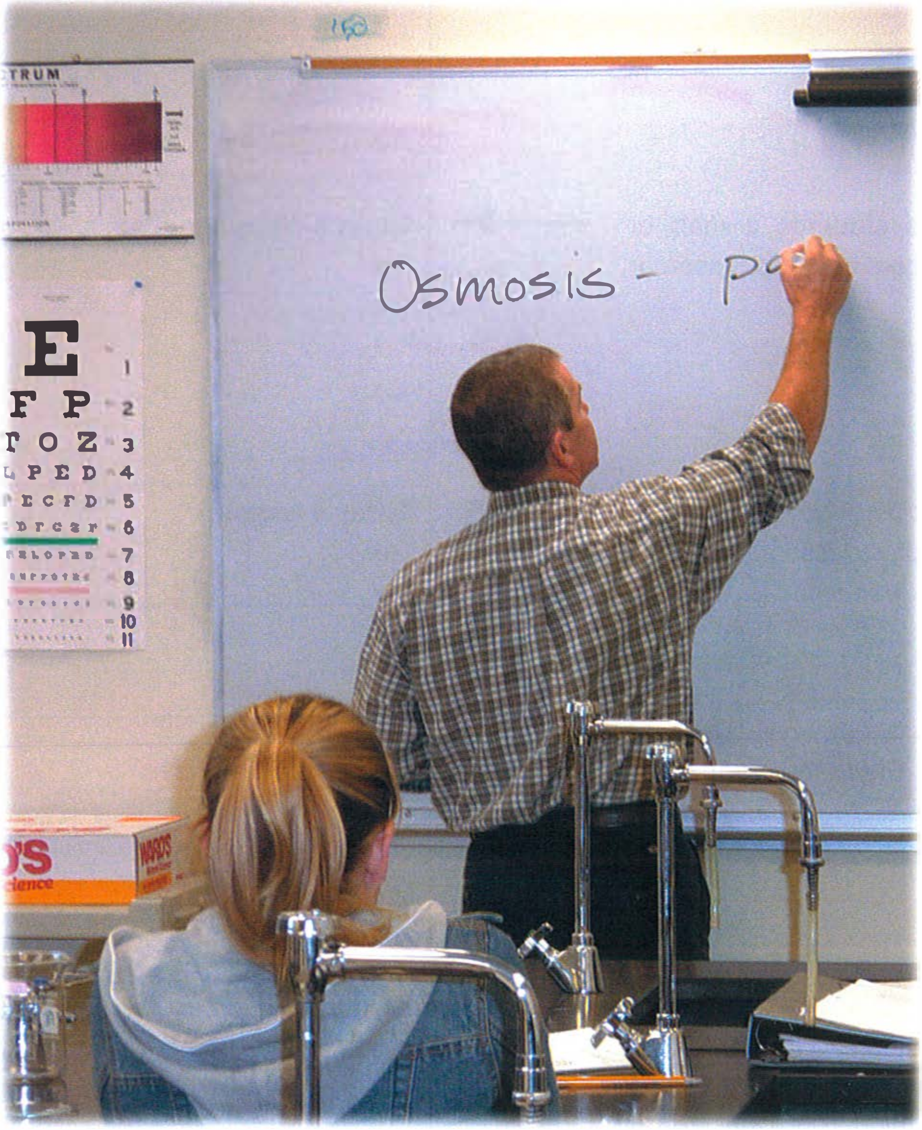


A WIDELY BENEFICIAL LESSON PLAN DESIGN

Activator: Prepare students for lesson by activating a personal connection to the topic. Check what students already know or want to know about a topic. →

Today's activator idea:

Learning Outcomes: Preview the major learning objectives for the class activity, lesson. →

Learning outcomes:

•
•
•
•
•

Agenda: Give students a map or agenda for upcoming class lesson or activity. →

Today's class agenda:

•
•
•
•
•

Lesson Plan: The information and activities for today's lesson. →

Today's lesson:

•
•
•
•

Summarizer: Students reconstruct what they have learned using a summarizing strategy. →

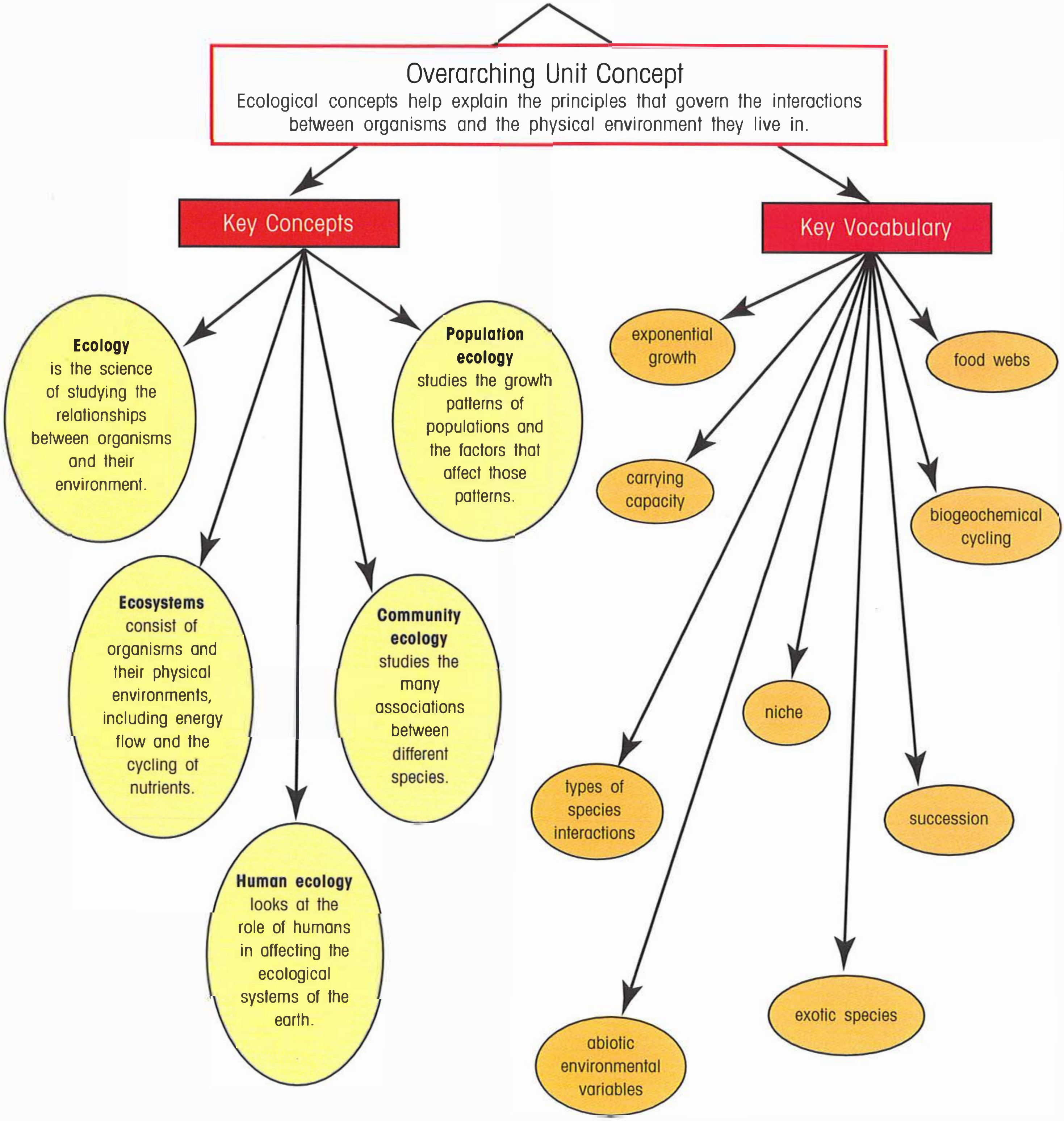
Today's summarizer:

Connectors: Students identify connections between earlier course concepts and new information. This might involve graphic organizers or analogies. →

Today's connector:

Reflection: Students reflect on the strategies and processes used to learn during the activity, class, and/or lesson.	**Today's reflection:**
Assignments: Explain new homework assignments or review ongoing assignments. Give students opportunity to ask for clarification.	**Assignments:**
Preview Next Class: Give a short preview of the next class, if possible.	**Next class:**

ECOLOGY COURSE MAP



Overarching Unit Concept

Ecological concepts help explain the principles that govern the interactions between organisms and the physical environment they live in.

Key Concepts

Ecology is the science of studying the relationships between organisms and their environment.

Population ecology studies the growth patterns of populations and the factors that affect those patterns.

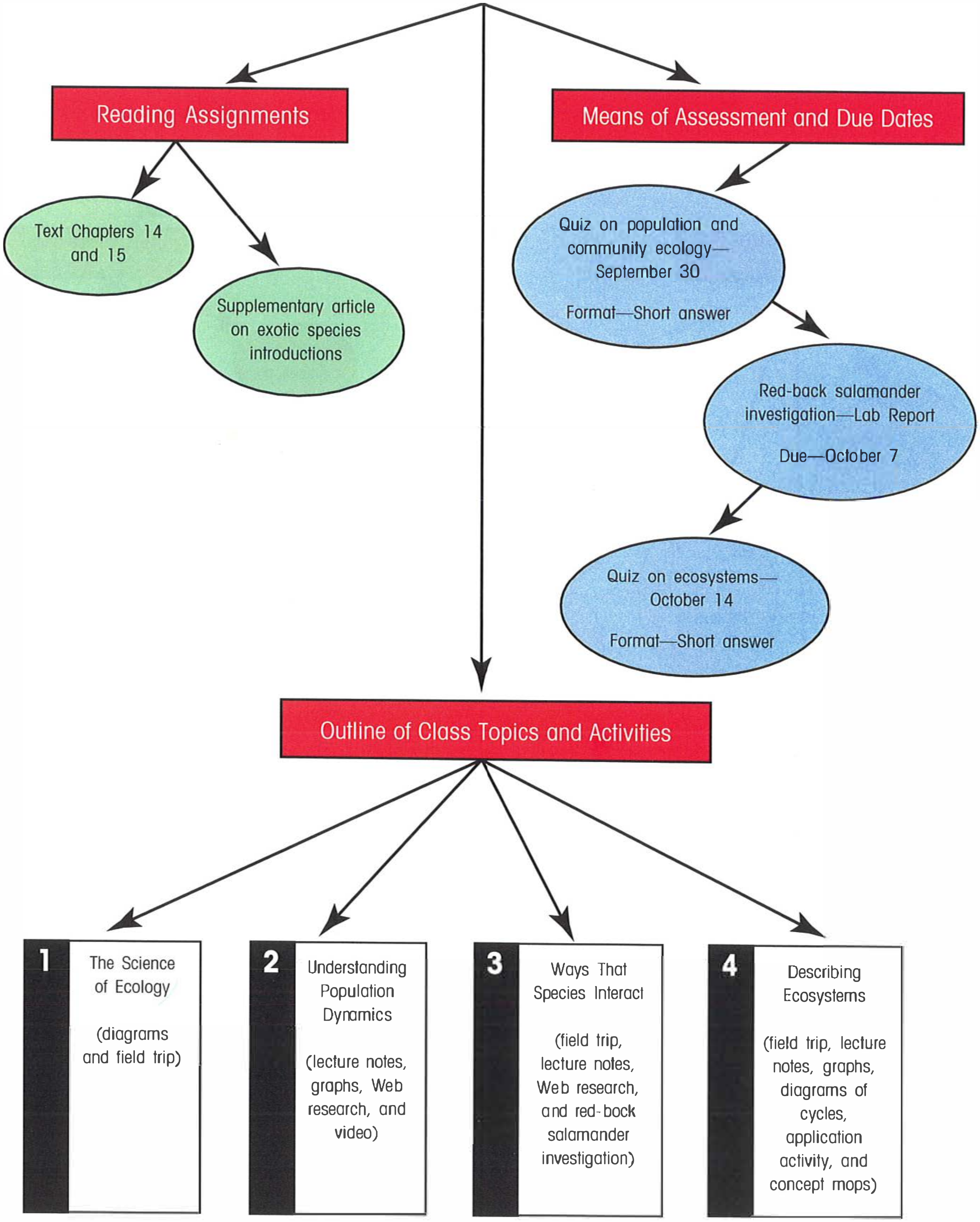
Ecosystems consist of organisms and their physical environments, including energy flow and the cycling of nutrients.

Community ecology studies the many associations between different species.

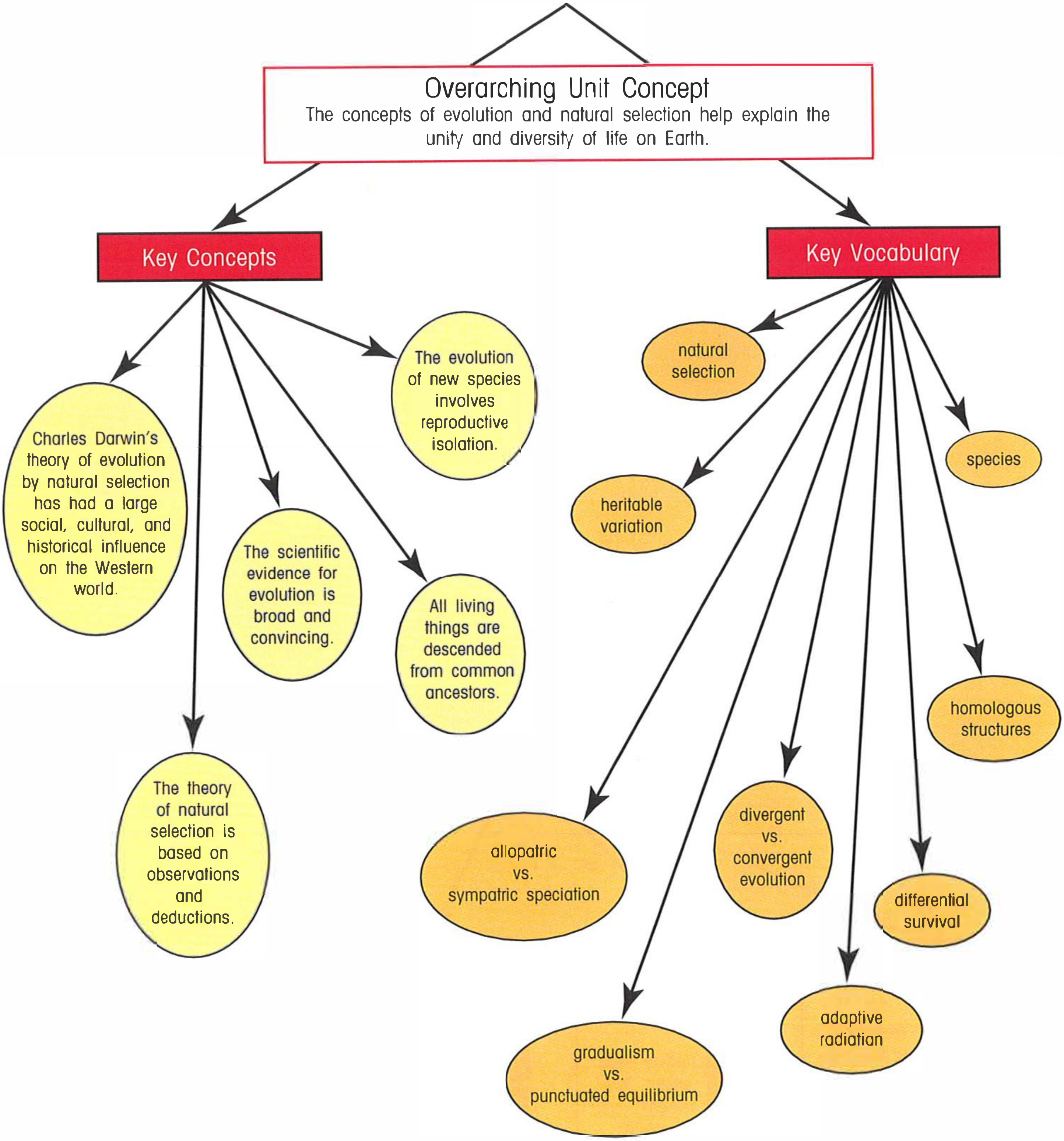
Human ecology looks at the role of humans in affecting the ecological systems of the earth.

Key Vocabulary

ECOLOGY COURSE MAP continued



EVOLUTION COURSE MAP



Overarching Unit Concept

The concepts of evolution and natural selection help explain the unity and diversity of life on Earth.

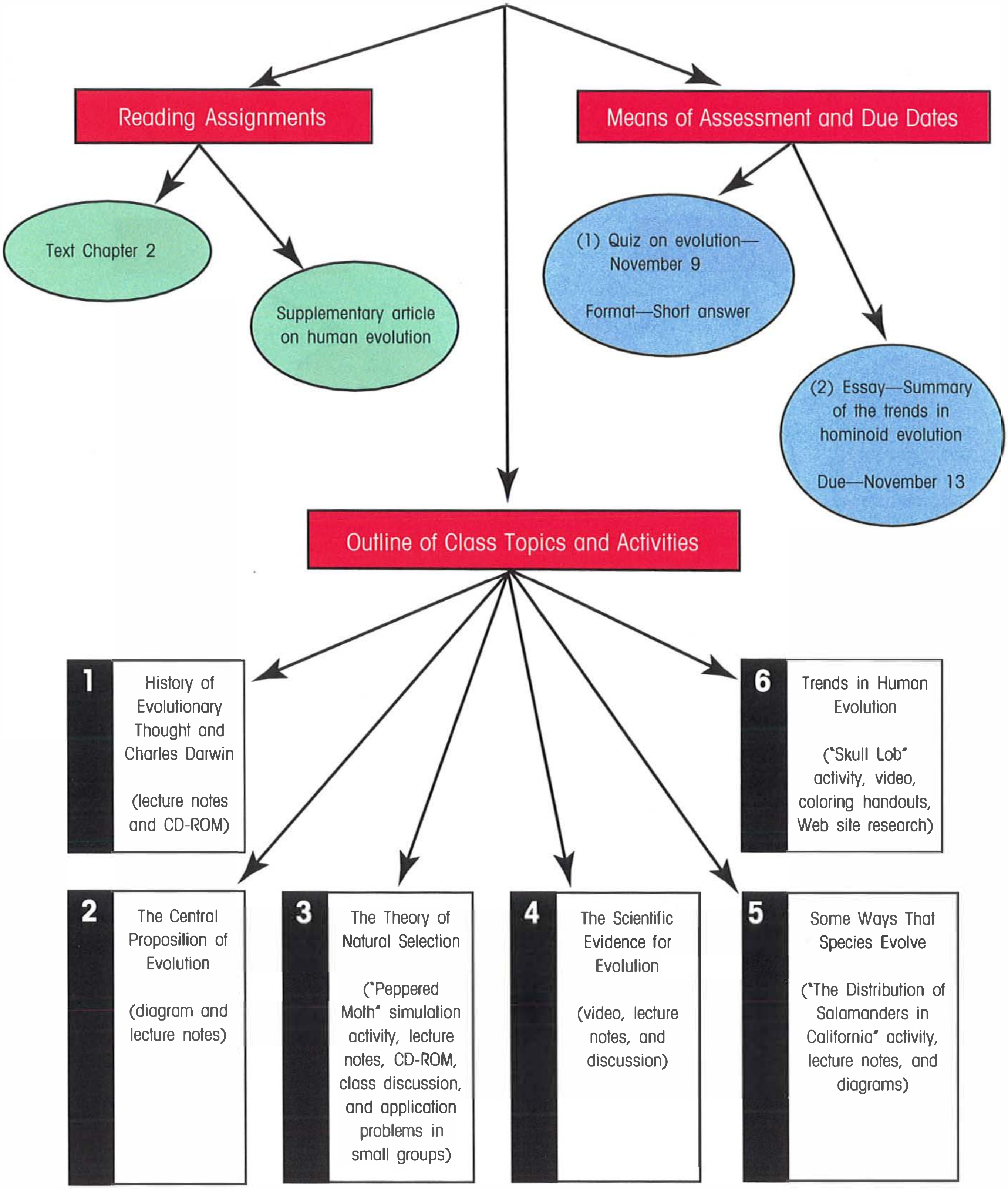
Key Concepts

- Charles Darwin's theory of evolution by natural selection has had a large social, cultural, and historical influence on the Western world.
- The theory of natural selection is based on observations and deductions.
- The scientific evidence for evolution is broad and convincing.
- All living things are descended from common ancestors.
- The evolution of new species involves reproductive isolation.

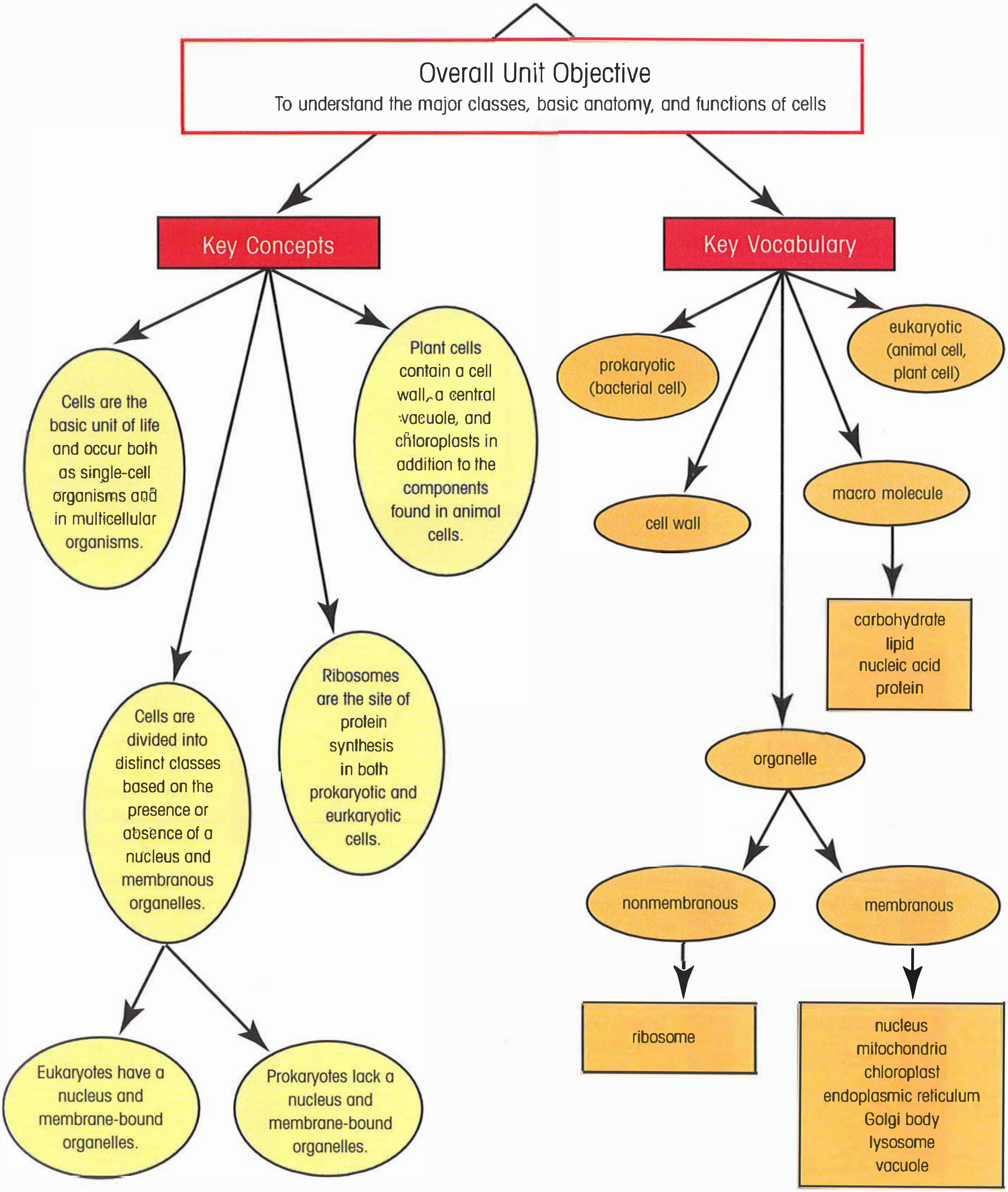
Key Vocabulary

- natural selection
- heritable variation
- allopatric vs. sympatric speciation
- gradualism vs. punctuated equilibrium
- divergent vs. convergent evolution
- adaptive radiation
- differential survival
- homologous structures
- species

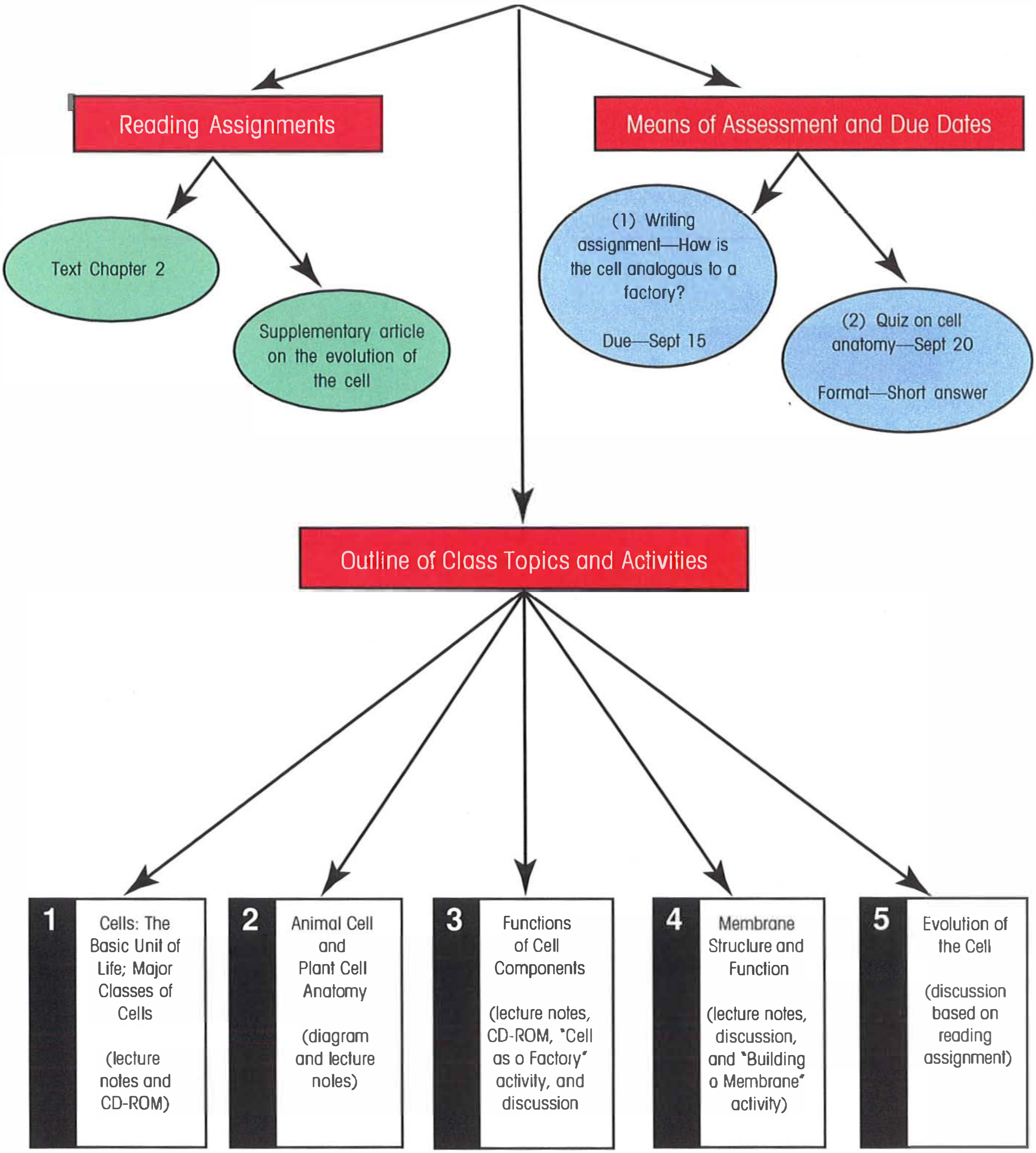
EVOLUTION COURSE MAP continued



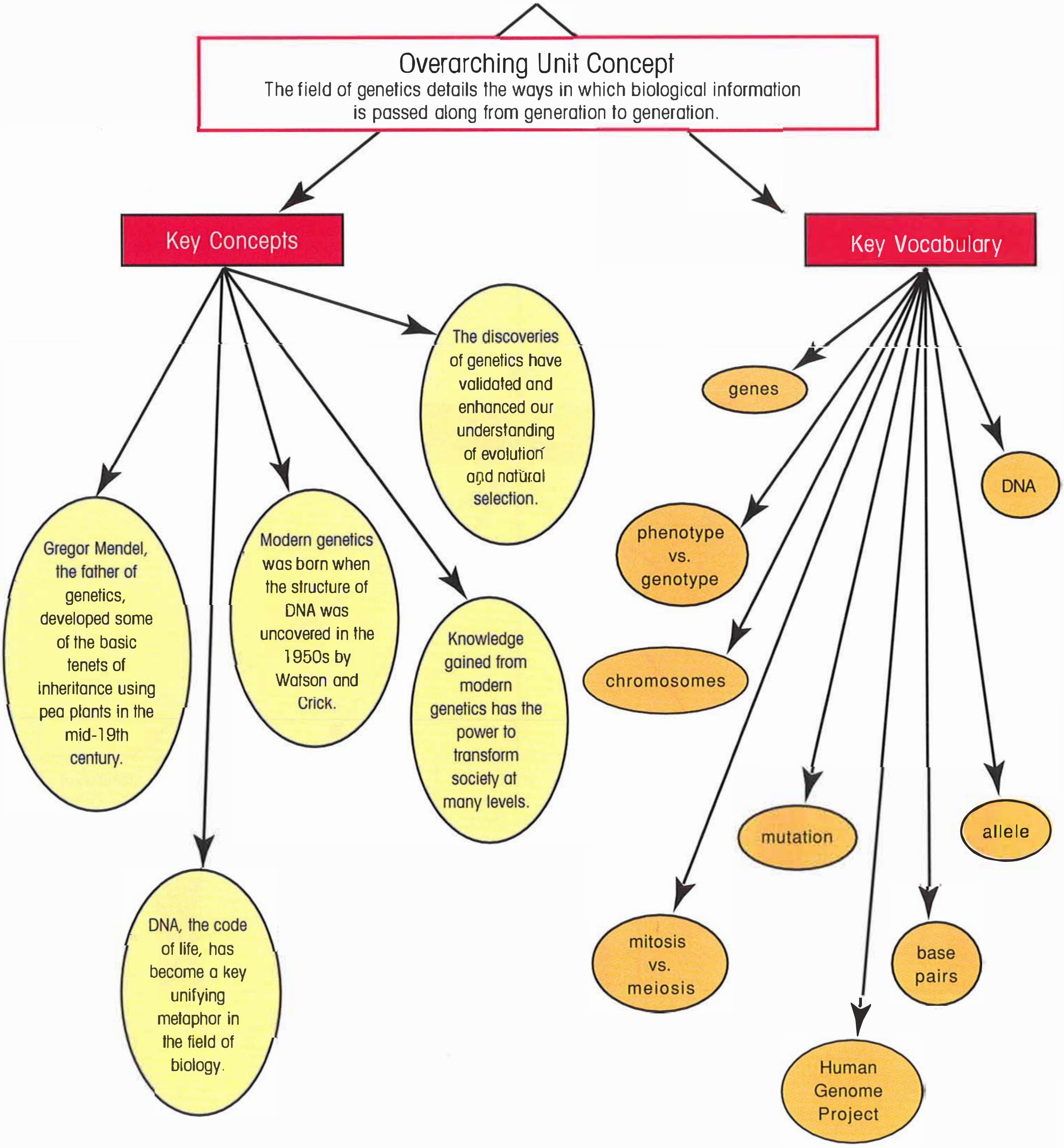
CELL BIOLOGY COURSE MAP



CELL BIOLOGY COURSE MAP continued



GENETICS COURSE MAP



Overarching Unit Concept

The field of genetics details the ways in which biological information is passed along from generation to generation.

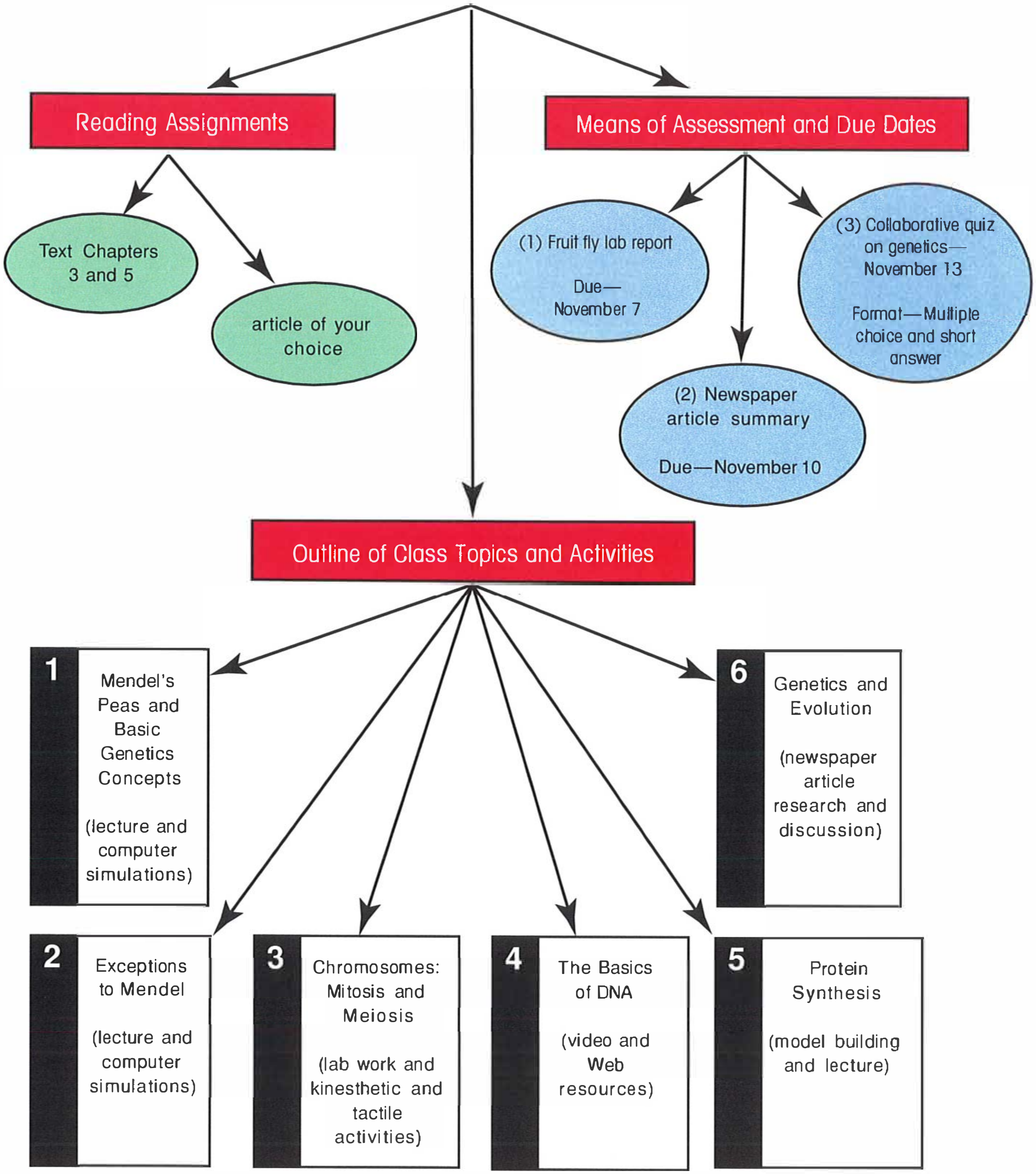
Key Concepts

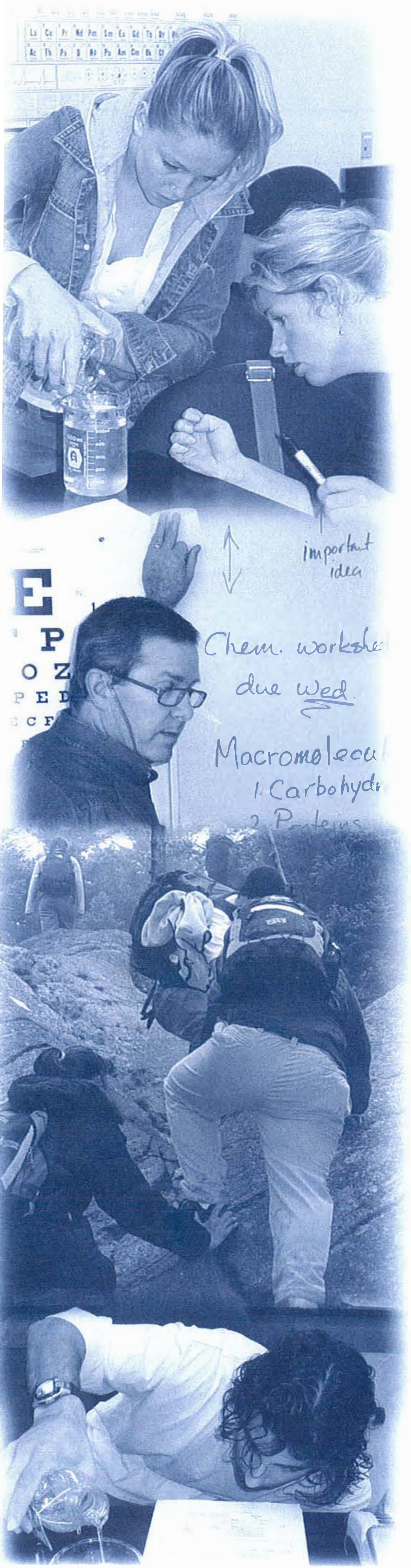
- Gregor Mendel, the father of genetics, developed some of the basic tenets of inheritance using pea plants in the mid-19th century.
- DNA, the code of life, has become a key unifying metaphor in the field of biology.
- Modern genetics was born when the structure of DNA was uncovered in the 1950s by Watson and Crick.
- Knowledge gained from modern genetics has the power to transform society at many levels.
- The discoveries of genetics have validated and enhanced our understanding of evolution and natural selection.

Key Vocabulary

- genes
- phenotype vs. genotype
- chromosomes
- mitosis vs. meiosis
- mutation
- Human Genome Project
- base pairs
- allele
- DNA

GENETICS COURSE MAP continued





3 GENERAL TEACHING METHODS

Introduction

The General Teaching Methods section illustrates and expands upon the Six Guiding Educational Principles and Widely Beneficial Practices outlined in Sections 1 and 2. It is divided into five subsections that are meant to provide a succinct overview of various teaching methods and techniques that can enhance the success of students with diverse learning needs. A short description of each subsection follows.

Starting a Course (page 29). The three subjects addressed are intended to help a biology instructor organize and begin a course in such a way that the diverse learning needs of students are taken into account.

Teaching Study Skills (page 51). Four articles with accompanying examples provide an overview of teaching some of the study skills necessary for student success in a typical biology course.

Using Varied Instructional Techniques (page 81). Seven teaching and learning techniques that serve the diverse learners in a biology classroom are described.

Assessing Student Performance (page 123). An overview of assessment is offered along with three specific areas of ideas and techniques for assessing student learning in the biology classroom.

The Biology Laboratory (page 157). This subsection presents the value of engaging students in biological inquiry, as well as some common struggles encountered by students with learning disabilities in laboratory settings. It ends with some suggestions for teaching and learning scientific inquiry.

Starting a Course: Course Organization

PROVIDING MAPS and itineraries of course work can help students understand the expectations of their instructors and help them preview the learning they will engage in. This can be helpful to all students but particularly to students with learning disabilities. It should happen at three levels: the semester or course level, the weekly or unit level, and the daily level.

Semester or Course Level

The most effective way to prepare students for the course journey they are embarking on is to provide and explicitly "uncover" the course syllabus. Spend time during the first day(s) of class discussing the academic expectations, learning objectives, course policies and procedures, key assignments, etc. that frame your course.

Most syllabi proceed in a linear, text-based form. Consider providing your syllabus in a more visually engaging format. **See page 32** for a graphically formatted example of an introductory biology syllabus made with Inspiration software. In addition, a course Web site can be a useful and appealing way for students to interact with the syllabus and its information.

Also, consider printing your syllabus on colored paper that will stand out from the rest of the paperwork flowing from your hands to the students'. This will heighten the awareness and importance of this document in the students' minds. To take this idea further, consider printing other key course documents on colored copier paper. Handouts such as specific assignment guidelines, advance organizers, or vocabulary lists would be good candidates for color-coding. Or an instructor could go all the way and distribute to students *all* documents on colored paper. For instance, genetics handouts could be blue, evolution handouts could be orange, and so on. This comprehensive system would make students' efforts to maintain course organization easier. Keep in mind, however, that this requires significant copier preparation by the instructor.

Another idea for making a course document like a syllabus less daunting is to break it up into several smaller documents, such as goals and objectives, grading, attendance policy, etc. For some students this may make access and use of these important items easier.

Key things to include in a biology course syllabus:

- Contact information (e-mail, phone, office hours, and location)
- Course objectives and key questions that frame the course
- Laboratory information (times, policies)
- Textbook information
- Grading policies
- Attendance policy
- Required assignments (due dates, how much grade value they carry, brief overview of special projects to be undertaken)
- Academic skills that will be taught or practiced
- Rough schedule of course topics and activities
- Suggested organization of course notebook
- Brief overview of teaching philosophy

Other Syllabus Tips

If possible, provide the syllabus to students before the course begins so that they can preview it on their own. This may help students with learning disabilities get a head start on preparing for the course.

Continue referring to and occasionally checking in with the syllabus throughout the course. This will ensure that students reflect on where they have been (they actually *are* making progress!) and keep their awareness on where they are going.

Unit-Level Course Maps and Weekly Plans

A unit-level course map combines the logistical elements of a course with some specific learning goals and unit-level vocabulary. See the section on "Widely Beneficial Practices" for more detail. Examples of unit-level course maps for units in ecology, evolution, cell biology, and genetics can be found **on pages 18–25.**

Just as providing course maps is helpful, presenting weekly maps adds to the preparedness, organization, and motivation of all students. Instead of counting on students to check the syllabus for themselves, explicitly supplying and previewing specific readings and assignments at the beginning of each week is more likely to be effective with students with learning disabilities. This can allow for changes in timing and planning that occur between syllabus preparation and later weeks in the course. Either on Friday or Monday, preview in-class and out-of-class activities for the week to come. It may be useful to prepare a handout of this information before class and distribute it to students during class. Using a different colored paper for these regular documents will also ensure that students will find and use them. Consider also using a more visual or calendar-based system to present this information. That may help those students with visual strengths follow the unfolding of the course more carefully. **See page 36** for two examples of a weekly plan for introductory biology. Another idea that may enhance student involvement in this process is to write down the plan on the board and have students copy it directly into their notebooks. Posting this same information on a course Web site is also recommended.

Daily Level: Agendas

A plan for each class meeting day also benefits students. Usually in the form of an agenda, this plan should provide more detail than the weekly plan and should be described at the beginning of each class. Post the agenda on a chalkboard, whiteboard, or poster before class begins, and keep it visually available for the entire class session, where it can be previewed and referred to as you progress through your sequence of activities. This will promote student focus and student clarity each day. **See Figure 3.1** for an example of a daily agenda.

Agenda suggestions:

- Make the style and location consistent so that the agenda becomes a routine for all.
- Cross off completed activities as you progress.
- If time runs short and the full scope of the agenda is not achievable, use the posted agenda to prioritize with students the remaining activities.
- Use the agenda as a tool to promote summarizing of the day's events/ideas/objectives.

Reference

Sections of this chapter have been adapted, with permission, from the following Landmark College publication:

Herbert, C., and S. W. Strothman. 2001. Considerations in classroom management. In *Promoting academic success for students with learning disabilities*, ed. S. W. Strothman, 51–81. Putney, VT: Landmark College.

MONDAY SEPTEMBER 15

Week preview and assignments for week

Define ecosystem

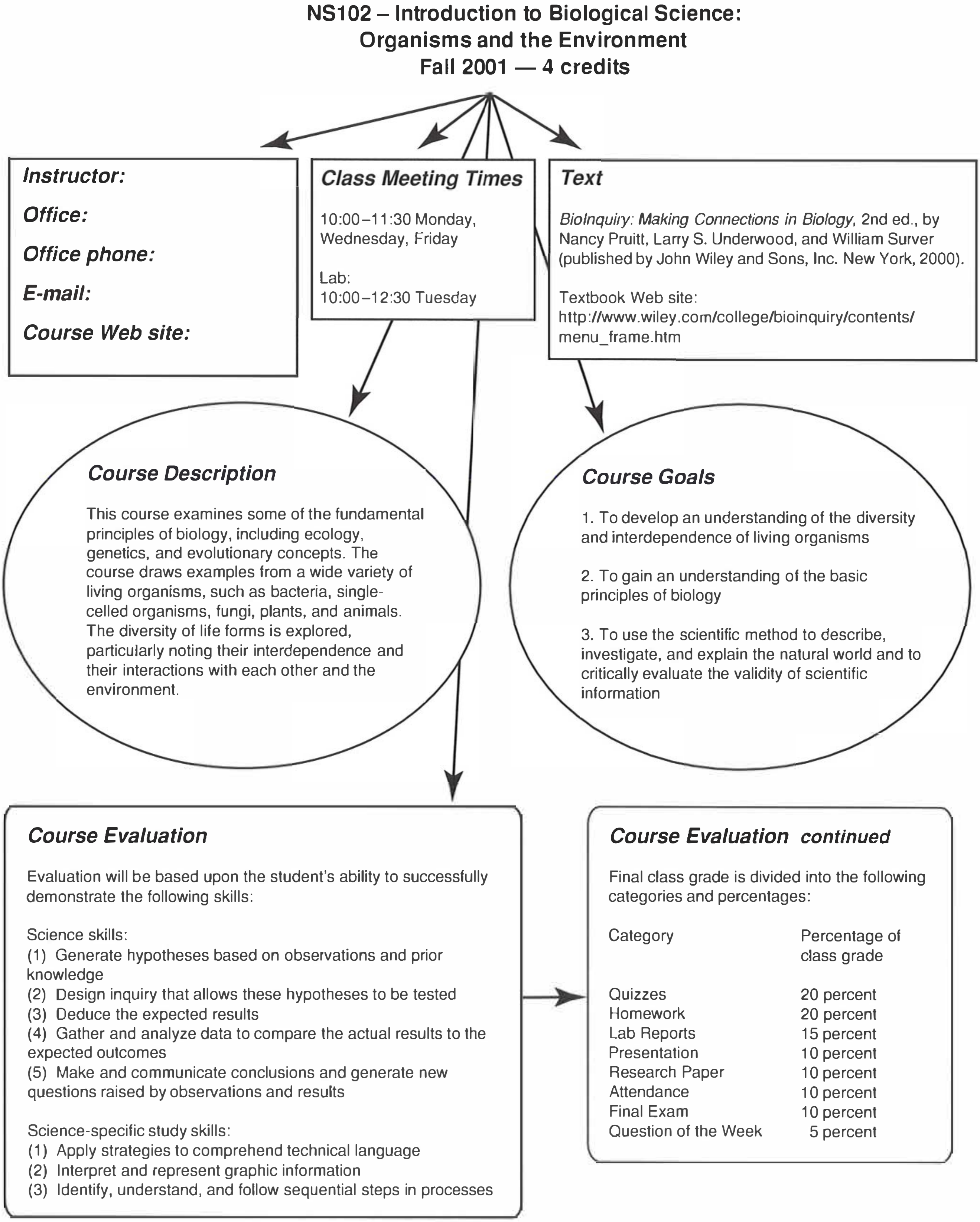
Watch video segment on pond ecosystem

Preview lab tomorrow

Apply understanding of ecosystems to make model with modeling material

Figure 3.1. An example of a daily agenda

EXAMPLE OF A GRAPHICALLY FORMATTED SYLLABUS



NS102 – Introduction to Biological Science:
Organisms and the Environment
Fall 2001 — 4 credits

Instructor:

Office:

Office phone:

E-mail:

Course Web site:

Class Meeting Times

10:00–11:30 Monday, Wednesday, Friday

Lab:
10:00–12:30 Tuesday

Text

BioInquiry: Making Connections in Biology, 2nd ed., by Nancy Pruitt, Larry S. Underwood, and William Surver (published by John Wiley and Sons, Inc. New York, 2000).

Textbook Web site:
http://www.wiley.com/college/bioinquiry/contents/menu_frame.htm

Course Description

This course examines some of the fundamental principles of biology, including ecology, genetics, and evolutionary concepts. The course draws examples from a wide variety of living organisms, such as bacteria, single-celled organisms, fungi, plants, and animals. The diversity of life forms is explored, particularly noting their interdependence and their interactions with each other and the environment.

Course Goals

1. To develop an understanding of the diversity and interdependence of living organisms
2. To gain an understanding of the basic principles of biology
3. To use the scientific method to describe, investigate, and explain the natural world and to critically evaluate the validity of scientific information

Course Evaluation

Evaluation will be based upon the student's ability to successfully demonstrate the following skills:

Science skills:
(1) Generate hypotheses based on observations and prior knowledge
(2) Design inquiry that allows these hypotheses to be tested
(3) Deduce the expected results
(4) Gather and analyze data to compare the actual results to the expected outcomes
(5) Make and communicate conclusions and generate new questions raised by observations and results

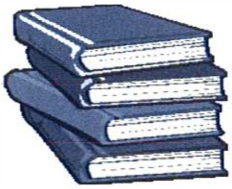
Science-specific study skills:
(1) Apply strategies to comprehend technical language
(2) Interpret and represent graphic information
(3) Identify, understand, and follow sequential steps in processes

***Course Evaluation** continued*

Final class grade is divided into the following categories and percentages:

Category	Percentage of class grade
Quizzes	20 percent
Homework	20 percent
Lab Reports	15 percent
Presentation	10 percent
Research Paper	10 percent
Attendance	10 percent
Final Exam	10 percent
Question of the Week	5 percent

Course Structure

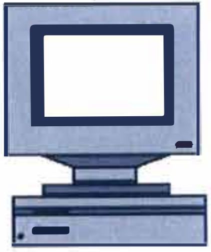


Reading

Readings will be assigned regularly from the text and supplemental sources. Students are expected to actively read assignments—highlight pertinent material, look up unknown vocabulary terms, take notes for review, generate questions/comments, etc. It is essential that all readings be completed on time so that you are fully prepared for discussions on the material.

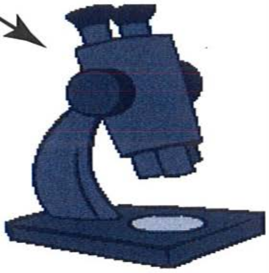
Writing Assignments

Writing assignments are given to help reinforce class discussions and textbook reading. Formal lab reports will be expected for each of the laboratory exercises performed. All written work must be typed, spell checked, and proofread for errors. Unless arrangements have been made with the instructor prior to the due date, late papers will be marked off 20 points and will not be accepted more than two weeks after the original due date. Writing assignments are often handed back with suggestions; they must be corrected and returned within a week for full credit. Unless prior arrangements have been made, written assignments must be turned in on their due date, even if the student is absent from class that day.



Research Paper

Each student will be required to research and write about a current biological "hot topic."



Laboratories

Labs will be held weekly for approximately 2-1/2 hours each time. Students are expected to attend every lab. Labs are an opportunity for students to apply and witness principles covered in class. Because of their nature, labs are often one-time-only events; therefore, it is imperative that students attend each lab. Formal lab reports will be expected after each lab.

Course Structure continued

Class Presentation

Working with a partner, each student will present a 30-minute class on a biological topic of the student's choosing. These presentations will take place toward the middle of the semester, and several class periods will be devoted to preparation.

Examinations

Quizzes will be given every two to three weeks. A cumulative final exam will be given.

Question of the Week

Each week a new question will be posted on the class Web site. The question will be related to that week's lecture, reading, or lab. Fill out the Internet form with your name and answer by the beginning of class on Friday every week.

Attendance

Please make an attempt to attend every class. Certain activities are impossible to duplicate, such as labs, group projects, presentations, and lectures. The entire week of class often revolves around what is covered in that week's lab; it is imperative that you attend lab every week. Attendance makes up 10 percent of your final class grade.

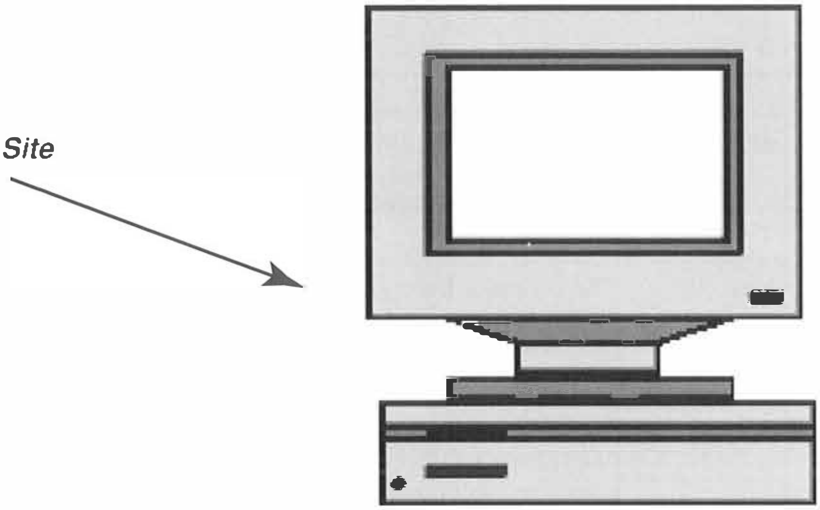
Tardies are defined as arrivals more than 5 minutes late to class.

Once a student has accumulated more than three class absences, one lab absence, or five tardies, or if it appears that a pattern of attendance problems is developing early in the semester, a meeting will be called between the student, the instructor, and the advisor to address the issue.

Preferably, a student should inform the instructor—via e-mail, phone, or in person—prior to an absence. If this is not possible, it is the student's responsibility to approach the instructor as soon as possible after the absence. If a student accumulates more than eight absences, he or she may be asked to withdraw from the class.

It is very important that you attend class—if you are not there, you will not get the information.

Course Web Site



The class Web site is an integral component of the class. All of the information in this syllabus can be found there, as well as other vital information.

Web resources for learning specific topics are located there, weekly assignments are listed, and the PowerPoint slides are uploaded following each lecture. Material will be added to the site often, and students are expected to visit the Web site regularly to take advantage of the resources that it has to offer.

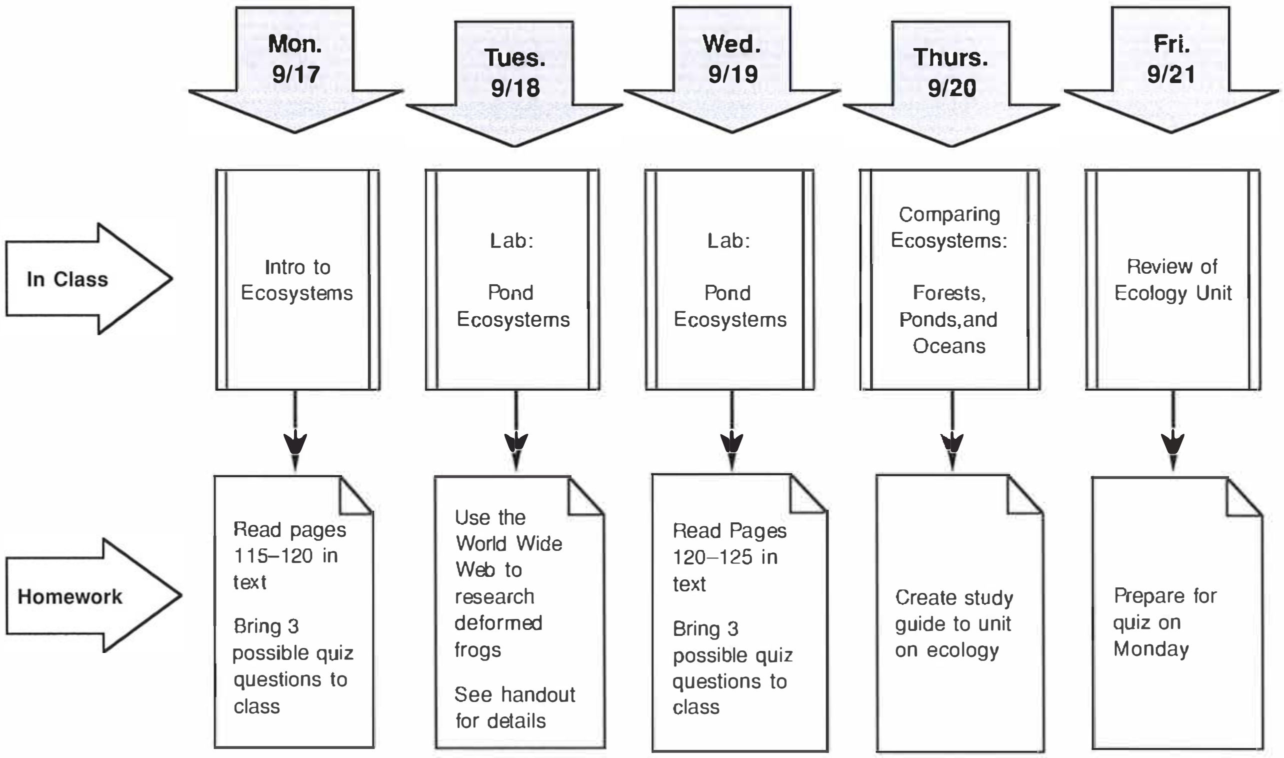
You must visit the course Web site at least once a week to answer the Question of the Week.

Class Schedule

DATES	TOPICS
August 28 – 31	Course Expectations & Study of Life
September 4 – 7	Scientific Method & Biodiversity
September 10 – 14	Biodiversity
September 17 – 21	Ecology
September 24 – 28	Ecology
October 1 – 5	Ecology
October 8 – 12	Evolution
October 22 – 26	Evolution
October 29 – November 2	Evolution
November 5 – 9	DNA
November 12 – 16	Genetics
November 19 – 23	Genetics
November 26 – 30	Genetics: Biotechnology
December 3 – 7	Review and Wrap-up

Weekly Plan for Introductory Biology		
Day	**In Class**	**For Homework**
Mon. 3/17	Intro to Genetics unit: *Journey into Life* animation; begin Biologica computer software work	Text Chapter 3, pages 55–65 See vocabulary sheet for key terms
Wed. 3/19	Continue with Biologica work; discussion and notes on basic genetics concepts	Text Chapter 3, pages 62–70 See vocabulary sheet for key terms, and answer review Question #6 on page 82
Fri. 3/21	Final day on Biologica work and continued discussion and notes on basic genetics concepts	Complete concept map assignment (see handout for details)

Weekly Plan for Introductory Biology



	Mon. 9/17	Tues. 9/18	Wed. 9/19	Thurs. 9/20	Fri. 9/21
In Class	Intro to Ecosystems	Lab: Pond Ecosystems	Lab: Pond Ecosystems	Comparing Ecosystems: Forests, Ponds,and Oceans	Review of Ecology Unit
Homework	Read pages 115–120 in text Bring 3 possible quiz questions to class	Use the World Wide Web to research deformed frogs See handout for details	Read Pages 120–125 in text Bring 3 possible quiz questions to class	Create study guide to unit on ecology	Prepare for quiz on Monday

Starting a Course: Learning Style Assessment

Introduction

Biology students do not all learn in the same way. Some have visual strengths; some have visual weaknesses. Some learn best through their hands; others learn best by listening. Learning happens through different modalities. Generally, a "learning style" is a learner's preferred method/mode/way of processing information. Bernice McCarthy (1987), David Kolb (1984), and other researchers have articulated some of the best insights into learning style. Howard Gardner's (1983) work on the theory of multiple intelligences offers yet another perspective on individual learners possessing different combinations of strengths and weaknesses.

Christina Herbert (2001), a professor at Landmark College, says that "students with learning disabilities often have pronounced strengths in processing information using alternative pathways, such as a visual, tactile, or kinesthetic approach, rather than relying on strictly auditory processing, which is often their weakest channel."

Why Designing Instruction with Learning Styles in Mind Is Important

If an instructor provides a learning environment that acknowledges varying learning styles,

- instruction will reach all of the students some of the time;
- student self-confidence and awareness will be enhanced;
- students are more likely to be motivated and engaged;
- students will also recognize a diversity of approaches to learning and the varieties of intelligence;
- students will learn to convert information that is less compatible with their learning styles to more compatible formats.

How to Understand and Address Learning Styles

Provide a survey at the beginning of the course to informally assess students' perceived strengths and difficulties.

This survey might include four parts: (1) a learning style inventory, (2) a study and academic skills self-assessment, (3) a survey of preferred classroom instructional activities, and (4) an open-ended written question.

(1) Learning Style Inventory

Web site addresses and descriptions for three different learning style inventories are provided below. All sites provide an immediate printable analysis of learning style preferences following completion of a series of questions.

http://www.metamath.com/lsweb/dvclearn.htm This site offers a learning style survey developed for college students by Catherine Jester at Diablo Valley College in California. It consists of thirty-two questions, allows for graded responses, and provides an immediate analysis of learning style preferences. In addition, a detailed list of numerous learning strategies that match the user's learning style is provided. This site is highly recommended because it's easy to use and offers valuable feedback.

http://www.engr.ncsu.edu/learningstyles/ilsweb.html The learning styles questionnaire found at this site was developed by Barbara Soloman and Richard Felder at North Carolina State University. The user must answer forty-four questions, choosing between two alternative answers even if both answers apply. A somewhat confusing graphical representation of learning style preferences along with a brief interpretation is generated upon completion of the questionnaire. Users have to go to other links to read descriptions of the various learning styles.

http://webster.commnet.edu/faculty/~simonds/styles/styles.htm The learning style questionnaire at this site was developed by the Learning Assistance Center staff at Capital Community College in Hartford, Connecticut. Users must complete a five-part survey (a total of thirty-five questions) to determine whether as learners they are auditory or visual, applied or conceptual, spatial or verbal, social or independent, and creative or pragmatic. Because users are required to keep track of their scores for each part (a mechanism is provided for this purpose), this survey is more complicated to use than the previous two. However, links and instructions are provided for obtaining both the interpretation of the results and suggested learning strategies.

Because these online surveys have a built-in analysis component, students and teachers can get immediate feedback on the inventory. With the results in hand, instructors will have a better sense of their students' strengths and weaknesses. For example, instructors might discover that the majority of their students are visually oriented; this knowledge could be immensely helpful in planning appropriate instructional strategies.

Nannette Smith (2001), of Bennett College in North Carolina, uses a learning style inventory as an exercise in developing hypotheses, collecting data, and drawing conclusions as part of a written lab report. **See Appendix A** for the full text of her article.

(2) Study and Academic Skills Self-Assessment

Teachers can also create and administer a study and academic skills self-assessment that will help them better understand their students. **See the Learning Questionnaire on page 40** for an example.

Suggested Analysis: One could simply tally up the number of "strength," "needs some improvement," and "needs much improvement" responses for each category across the class and convert each to a percentage. For example, an instructor might discover that 50 percent of the class reports that their test taking "needs much improvement." Or an instructor may find that 90 percent of the students perceive their abstract comprehension skills to be a strength. All of this information would be helpful in identifying the specific skill instruction area that may or may not be necessary to include in the course.

(3) Survey of Preferred Classroom Instructional Activities

A third component could be a survey of the kinds of classroom activities that students think support their optimal learning. **See the Learning Questionnaire on page 40** for an example.

Suggested Analysis: One could simply tally up the number of "preferred," "not preferred," and "neutral" responses for each category across the class and convert to a percentage. For example, an instructor might discover that 15 percent of the students in a class claim that small-group activities are *not* preferred or 90 percent claim that hands-on activities/labs are a preferred activity. Again, this information would be helpful in designing day-to-day activities in the class.

(4) Open-Ended Question

It is also helpful to give students a chance to tell you something in their own words that they feel is important for you to know. This may be done orally or in writing, and may reveal some valuable information about students that the grids and surveys missed. **See the Learning Questionnaire on page 40** for an example of an open-ended question.

Possible discoveries include finding that one student has failed his last three biology classes. Or you may discover that another student is a mathematical wizard and wants to apply that to her biological studies.

Further Ideas

Once students have their results from the learning questionnaire and/or learning style inventory, hold a class discussion to validate the diverse learning styles and needs of members of the class. Make them aware of the design of your course and how it will attempt to serve the diversity of learners enrolled.

References

Gardner, H. 1983. *Frames of mind: The theory of multiple intelligences*. New York: Basic Books.

Kolb, D. A. 1984. *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.

McCarthy, B. 1987. *The 4MAT system: Teaching to learning styles with right/left mode techniques*. Barrington, IL: About Learning.

Smith, N. 2001. Identifying and using learning styles to facilitate instruction. In *College pathways to the science education standards*, ed. E. D. Siebert and W. J. McIntosh, 6–7. Arlington, VA: NSTA Press.

Herbert, C. 2001. Making college classrooms accessible to students with and without learning disabilities. In *Promoting academic success for students with learning disabilities*, ed. S. Strothman, 1–26. Putney, VT: Landmark College.

LEARNING QUESTIONNAIRE

Name: ______________________________

The following is designed to help your instructor understand more about you as a student and learner.

A. Study and Academic Skills Self-Assessment

Rank the following skill areas as to whether they need lots of improvement, need some improvement, or are a strength for you.

Area	Needs Much Improvement	Needs Some Improvement	A Strength for Me
Abstract comprehension			
Note taking			
Test taking			
Reading a science textbook			
Vocabulary acquisition			
Lab writing			
Work completion by due dates			
Attendance			
Time management			
Organization of class materials			

B. Survey of Preferred Classroom Instructional Activities

Check the following kinds of instructional activities as Preferred, Neutral, or Not Preferred.

Instructional Activity	Preferred: This strongly supports my learning	I feel Neutral about this kind of activity	Not preferred: This kind of activity does not support my learning
Abstract comprehension			
Lecture using overhead, chalkboard, or computer/projector			
Full class discussion			
Teacher demonstrations of scientific concepts			
Small-group activities/discussion with classmates			
Student laboratory activities/hands-on work			
Videos			
Computer-based work			
Long-term independent projects			

C. Student Background

In a few sentences, please share whatever you would like to about yourself as a learner/student. What do you want a new teacher to know about you?

Starting a Course: Student Background Knowledge

LEARNING STYLE surveys and assessments provide information on general student learning across the curriculum. In addition to gathering this data, administering an informal assessment of students' preexisting knowledge of biological concepts and of the scientific method is also recommended. Both contemporary science education theory and Landmark teaching principles agree that effective teaching and learning begin with an understanding of students' prior knowledge and skill levels. According to the American Association for the Advancement of Science's educational reform initiative Project 2061 (AAAS 2001), many science concepts are inconsistent with students' preexisting beliefs about the biological and physical world. It is therefore the teacher's role to understand the preconceptions or prior knowledge students brings with them to class, and to guide them to a new and superior level of conceptual understanding.

It is suggested that instructors informally assess student background both at the beginning of a course and at the beginning of each new unit of study. The assessment at the beginning of a course should be more general and should include a component on student understanding of the scientific method. The assessment at the beginning of each unit should be more specific to that unit. The diagnostic information gained through these assessments offers a teacher some insightful guidance in designing the instructional sequence for the particular group of students. These assessments also activate student thinking and focus on the new subject by forging a connection between what students already think and believe and what they're about to be taught. Carefully attending to preconceptions is therefore as important to students' learning as it is to a teacher's diagnostic understanding.

It is important to be explicit with students about the purpose of any technique or activity intended to check their preconceptions. Let them know not only *what* you are asking them to do, but also the *reason* you are asking them to do it: recognizing prior conceptions is an important academic skill. Also, it is essential to impress upon students that their responses to background assessments will in no way affect their grades.

Biology Background Assessment at Beginning of Course

Carry out an informal assessment that allows students to express their preexisting knowledge in different ways: individual written responses, group discussion, and a small-group task.

Written Responses

Choose one or a few different formats for gathering written responses on core biological concepts and background. **See page 47** for a reproducible example of a background assessment based on written responses. Use a format and content that is specific to your course objectives.

Group Discussion

Take twenty to thirty minutes to hold a class discussion.

1. Brainstorm some of the current controversial issues in the field of biology. The teacher records responses on poster paper, chalkboard, or computer (with projection device) in a location visible for the entire class to see.
2. Have the class choose two of the controversies to discuss in more detail. Lead the students in discussion to ascertain what they know and don't know about the issues chosen, what their viewpoints are, and how they articulate their positions.

The purpose is to assess background knowledge, observe discussion/oral expression skills, and get a sense of group dynamics. This can be helpful in planning future activities and can inspire those students who like to talk about ideas.

Small-Group Task

Ask students to work in teams (two-person teams are ideal) to complete the following tasks:

Option A: Create/draw a visual model of a cell. Illustrate, color, and identify parts.

Provide markers, large sheets of paper, and whatever may assist students in this task.

Option B: Use the materials provided to build an ecosystem.

Provide some form of modeling materials: clay, colored paper clips, Tinkertoys, paper. While this may seem like a stretch for students to connect abstract tactile materials to biology, it can be surprising and illuminating to see what students can express when they think through a hands-on activity.

For both of these activities, build in a short, informal presentation by the students, so they can show their work and link language to visuals and models.

The purpose of this activity is to see student conceptions of key biological phenomena, and to see how students express their understanding through a medium that is not language based. The idea is not to spend hours doing this; rather, give the students a twenty-minute opportunity to demonstrate what they already know.

Biology Background Assessment at Beginning of New Units

Use some of the following techniques for drawing out prior knowledge at the beginning of new units of study. The techniques that follow start with the simplest to implement and progress to the more involved.

Freewriting

Freewriting is an informal way to get students to put down on paper their prior knowledge and preconceptions. Here are some guidelines to share with students:

> *Write without regard to formality or correctness. Don't worry about spelling, punctuation, or perfect sentence structure. Once you put your pen/pencil on the page, do not lift it off until the time is up. If you can't think of anything to write, keep repeating a word or phrase until something pops into your head.*

To apply this technique, simply give students a writing prompt and allow them several minutes to freewrite their responses. Either follow this with a class discussion or collect responses for later assessment. One advantage of freewriting is that it allows time for those students who are slow information processors or weak with expressive language to get their thoughts out on paper before discussing them.

Example: Freewrite a response to the question "How does a cell get and use energy?"

Brainstorming or Mind Mapping

Two other similar techniques for assessing prior knowledge and preconceptions are *brainstorming*, a linear free-flowing list of topic ideas or attributes, and *mind mapping*, a visually based nonlinear diagram of ideas or attributes about a topic. As in freewriting, students are given a prompt that requires them to activate and express their prior knowledge about a topic. **See Figure 3.2.**

Example of a prompt: "Charles Darwin"

"What You Know" Charts

A *What You Know chart* is a variation on the KWL (**K**now, **W**ant to know, **L**earned) chart, a graphic organizer commonly used in K–12 curriculum areas. (**See Figure 3.3** on the following page.) This prior knowledge assessment challenges students to identify not only their *firm* preconceptions ("what you know") but their *provisional* preconceptions

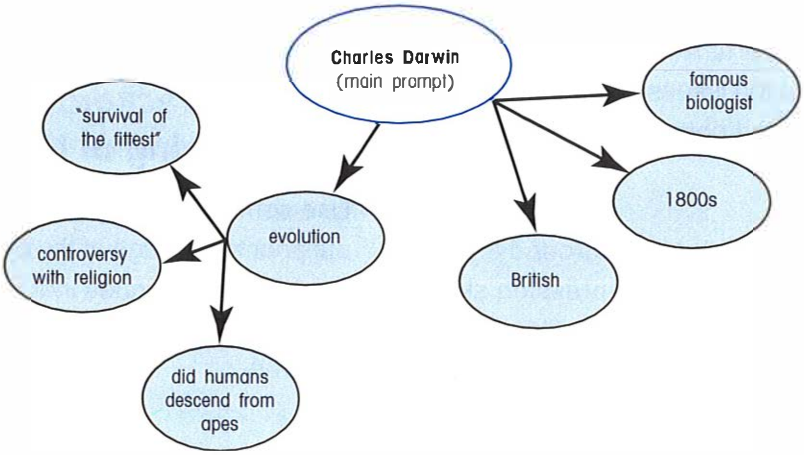


Figure 3.2. An example of a student-made mind map created with Inspiration software

What You Know Already about Genetics	What You Think You Know but Are Not Entirely Sure about Genetics	Questions You Would Like Answered about Genetics
Involves things called genes	Humans can be cloned	What does DNA stand for?
Involves DNA	Recessive genes are uncommon	Do I get half of my genes from each parent?
Invented by Mendel		How do genes change?
Makes us who we are (physical characteristics)		
Can produce cloning		

Figure 3.3. An example of a *What You Know* chart

("what you think you know but aren't entirely sure"). In addition, it asks them to consider what they would like to know about a topic, which is a more open-ended prompt.

Pre-Tests

A *pre-test* is a test-like survey that draws out student preconceptions and prior knowledge. Use a pre-test in a form that is easily interpretable, such as true/false or fill-in-the-blank. Make sure that the pre-test is simple and does not overwhelm students with terminology they do not know. It can also be helpful after students complete pre-tests to go over their responses as a class, so that the instructor can probe their conceptions further and give students with stronger oral expression skills a chance to show their strength. **See page 49** for an example of a pre-test for an evolution unit.

Model or Diagram Building

For students who are visual or tactile learners, a diagram or model may be an effective way to elicit prior knowledge. Supply students with a specific prompt and the materials necessary to build a model or draw a diagram. Some effective modeling materials include colored pencils and paper, crayons, colored pipe cleaners, modeling clay or wax, Tinkertoys, Legos, or any other items that are flexible and/or "buildable."

Examples:

(a) With the materials provided, build a model of either a plant, an animal, or a bacteria cell.

(b) Draw a model of a cell, plant, animal, or bacteria.

Demonstrations of Phenomena

A demonstration that asks students in advance what they predict might happen and why is another preconception activating technique. This technique may follow a simple formula: "What will happen if _______, and why?" To make it work, an instructor must model or preview the demonstration without actually doing it, then elicit from all students predictions of what they expect to observe and why. The predictions could be made individually in writing or through group discussion by the whole class or by teams. Then carry out the demonstration (either the teacher performs the demonstration for the whole class, or several student teams perform their own demonstrations) and compare predictions to results. **See the sidebar** for an example of a demonstration.

EXAMPLE DEMONSTRATION: PRECONCEPTIONS ABOUT OSMOSIS

Have a hard-boiled egg(s) that is presoaked in vinegar so that the shell is dissolved. To model the demonstration:

- Carefully blot the egg dry with a paper towel and measure its mass in grams.
- Share mass with the students.
- Place three drops of green food coloring* in a beaker.
- Place the egg in the same beaker and cover it with a distilled water solution.
- Give this preconception prompt: *What do you predict will happen to the mass of the egg after soaking in the solution? Develop a scientific explanation for your prediction. Discuss predictions and explanations.*
- Wait 5 minutes (or more if discussion is still going), remove the egg from the beaker, blot dry, and measure the mass again.
- Compare predictions (preconceptions) with actual results.
- Discuss discrepancies between prediction, explanations, and results.

** The food coloring allows further predictions and discussion concerning the rate of water movement.*

Case Studies

Give students a biological case study relating to a new unit of study and ask them to draw some conclusions about the topic, event, or phenomenon within the case study. Student responses could be discussed or written. The Web site National Center for Case Study Teaching in Science (http://ublib.buffalo.edu/libraries/projects/cases/case.html) has a wealth of options to choose from.

Give Students Options

When possible, offer students a choice of the techniques described above to show their knowledge. This encourages them to acknowledge and work from their strengths.

Conclusion

An instructor can use these techniques to get a general sense of the kind and depth of science and biology background knowledge students carry with them. Investing some time in administering these informal assessments will pay off with stronger student interest and helpful diagnostic information that informs effective teaching practices.

Reference

American Association for the Advancement of Science (AAAS) (Project 2061). 2001. *Designs for scientific literacy.* New York: Oxford University Press.

BIOLOGY BACKGROUND SURVEY

(Beginning of Course)

Name: ______________________

Please complete the following:

Multiple Choice: (circle a, b, c, or d)

1. Charles Darwin is best known for his work:
   a. with cells in the 19th century
   b. inventing modern microscopes
   c. suggesting a theory of evolution
   d. discovering the structure of DNA

2. A species can be defined as:
   a. a group of related organisms
   b. a group of organisms that can interbreed successfully and produce fertile offspring
   c. a group of organisms that have the same genes
   d. a group of organisms that share similar physical characteristics

3. Viruses are:
   a. the simplest living organisms
   b. infectious particles
   c. thought to be nonliving entities
   d. a and b
   e. b and c

4. Ecology is best described as the study of:
   a. species diversity
   b. the interactions of species and the environment
   c. natural environment
   d. ecosystems

5. Cells have many membrane-bound substructures called:
   a. organelles
   b. molecules
   c. DNA
   d. proteins

(over)

Short Answer

1. Describe how scientists study the natural world using the scientific method.

2. You are setting up an experiment to study the effects on tomato seedlings of adding varying concentrations of salt in the watering solution. Your teacher suggests you set up a "control" as part of your experiment. What does this mean?

AN EVOLUTION PRE-TEST*

Directions: Label each statement as either True, False, or Opinion

_________ 1. The evolution of major groups of animals and plants is an observed fact.

_________ 2. Evolution was first proposed and explained by Charles Darwin.

_________ 3. Evolution is also known as "natural selection."

_________ 4. Evolution is something that happens to individual organisms.

_________ 5. Evolution is a totally random process, a series of "accidents."

_________ 6. In order to accept evolution as a valid explanation, you cannot believe in God.

_________ 7. There is actually very little evidence for evolution.

_________ 8. Dinosaurs lived during the time of early humans.

_________ 9. Evolution involves individuals changing in order to adapt to their environment.

_________ 10. Science can productively study the past, based on evidence, so evolution is a proper subject for science.

---

* From *Evolution and the Nature of Science Institutes* at http://www.indiana.edu/~ensiweb/lessons/ev.surv.html

Teaching Study Skills: Master Notebooks

Overview and Rationale

A *master notebook* is an organizational system used to maintain and study all course-related materials. It can be a useful course management tool for introductory biology students. **Figure 3.4** shows some of the features of the system.

The master notebook is

- a portable filing system and reference source for class materials;
- a step-by-step study process that builds in successful study techniques;
- a strategy for increasing comprehension and retention in preparation for tests or other assessments;
- a system for organizing all aspects of a course;
- a technique that demands an active learning approach; and
- a helpful tool for developing time management skills.

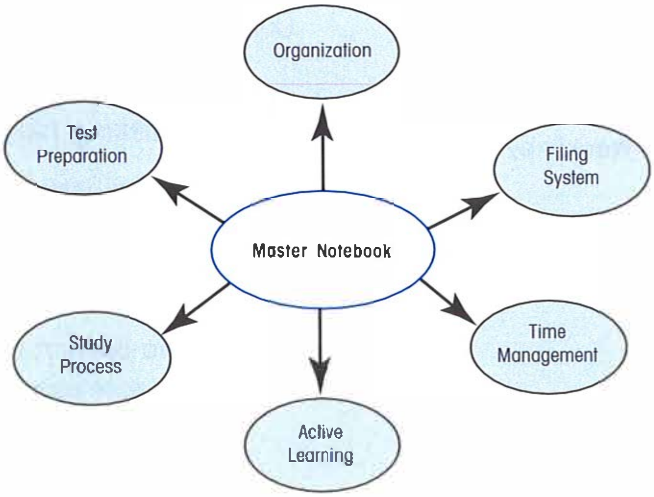


Figure 3.4. The purposes of a master notebook system

Implementing a master notebook system in a biology course can benefit all students' course management. The system requires that students be active participants in the organizing of their course materials. Consequently, maintaining a master notebook enhances students' metacognitive skills. Explaining the rationale behind this system helps motivate students to use this approach. As students become more experienced learners, they often adapt the system to meet their particular learning styles. In order to stay organized, students are advised to maintain a separate master notebook for every course they take.

Organization of the Master Notebook

There are several ways to organize the physical layout of the master notebook. We offer two examples below, but teacher preferences and student needs may make other layouts more practical and appropriate.

Layout One

Figure 3.5 shows one possible layout for a master notebook. The *left* side contains

- the course syllabus or outline,
- assignments (provided weekly by instructor), and
- the semester calendar (optional).

The *right* side contains

- 2-column note paper,
- tab dividers/pocket keeper,
- class notes in chronological order by date,
- handouts: dated and hole-punched (cross-referenced to notes),
- tests, quizzes: for review, to analyze test-taking skills,
- written assignments, and
- completed homework due today.

Layout Two

An alternative to the system described above would be to organize the right side of the notebook by topic. For instance, a biology course might pursue five topics over the course of a semester: cell biology, genetics, evolution, botany, and zoology. Each topic would get a unique section, and all materials (notes, handouts, labs, etc.) related to that topic would be filed chronologically within that section. **See Figure 3.6** for an example of this layout.

Note Taking and the Master Notebook

Utilizing a note-taking system is just as important as the physical layout of the master notebook and is key to maximizing its effectiveness. The following system is based on the Cornell Method of note taking, developed by Walter Pauk (2000) at Cornell University.

Step 1—Taking Notes in Class

Here are some basic guidelines for taking notes:

- Give the lecture a title and date, and number the page
- Use two-column note paper, or create two-column note paper by drawing a vertical line approximately one-third over from the left edge of plain note paper (**see Figure 3.7,** the "unrevised" example)

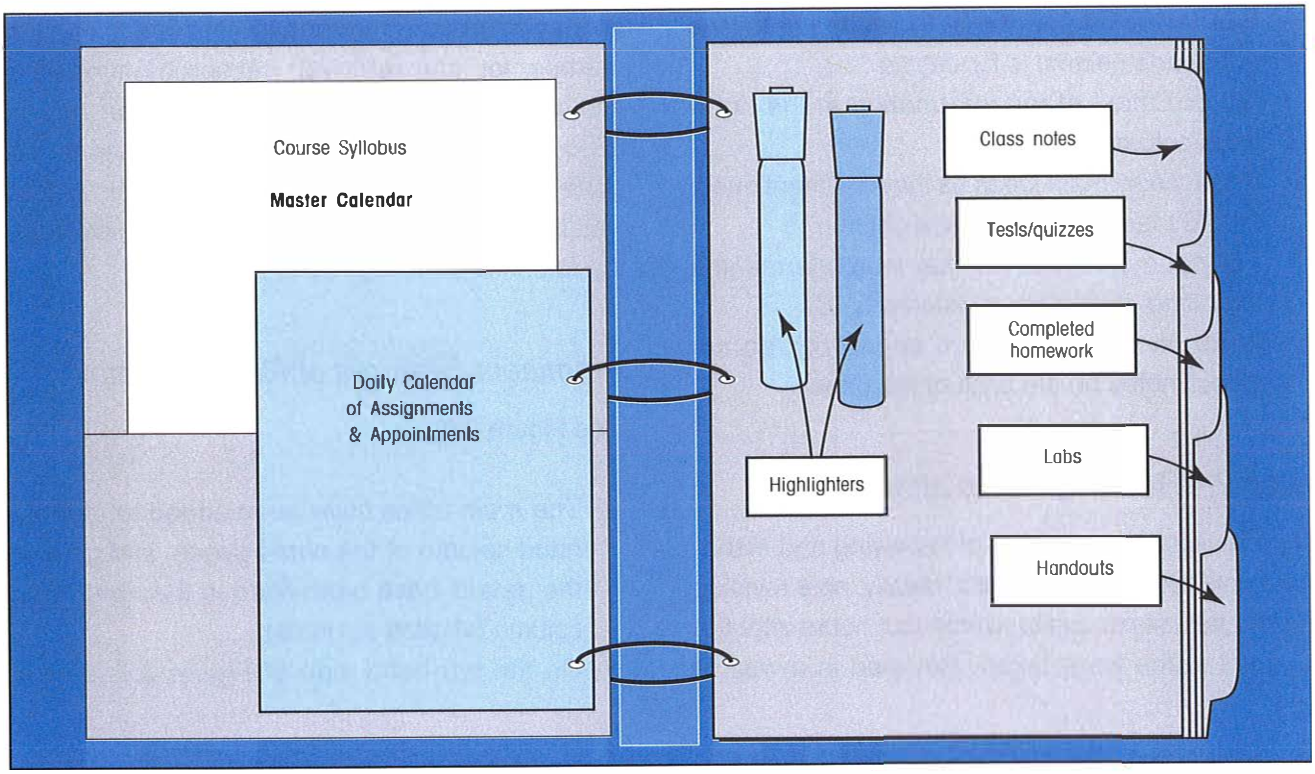


Figure 3.5. A possible layout for the master notebook

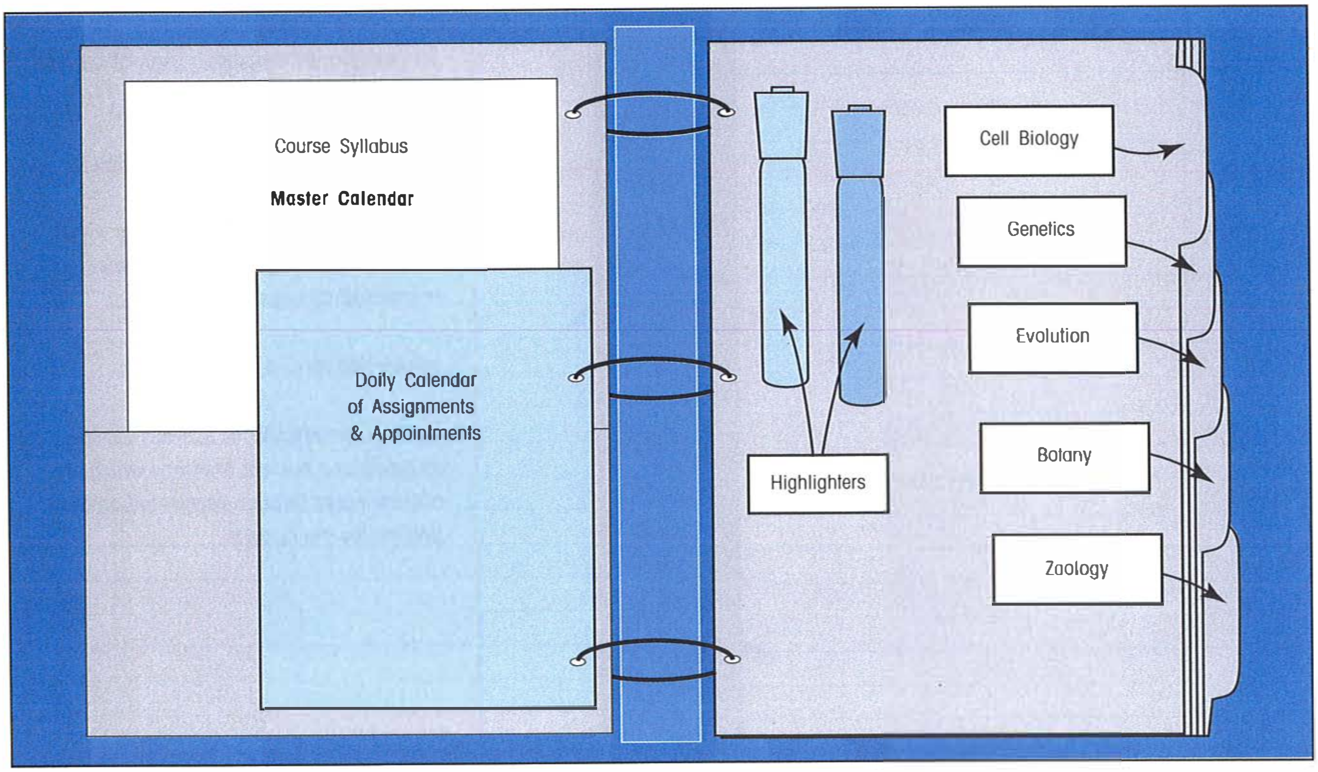


Figure 3.6. An alternative layout for the master notebook

- The left-hand column is for main ideas; the right-hand column is for details
- Record most of the information in the right-hand column
- If you "hear" main ideas as they are mentioned, record these in the left-hand column
- Pull out main ideas and key words/terms at a later time, during the revision process
- Write on one side of the page only; do not record notes on the back of the paper

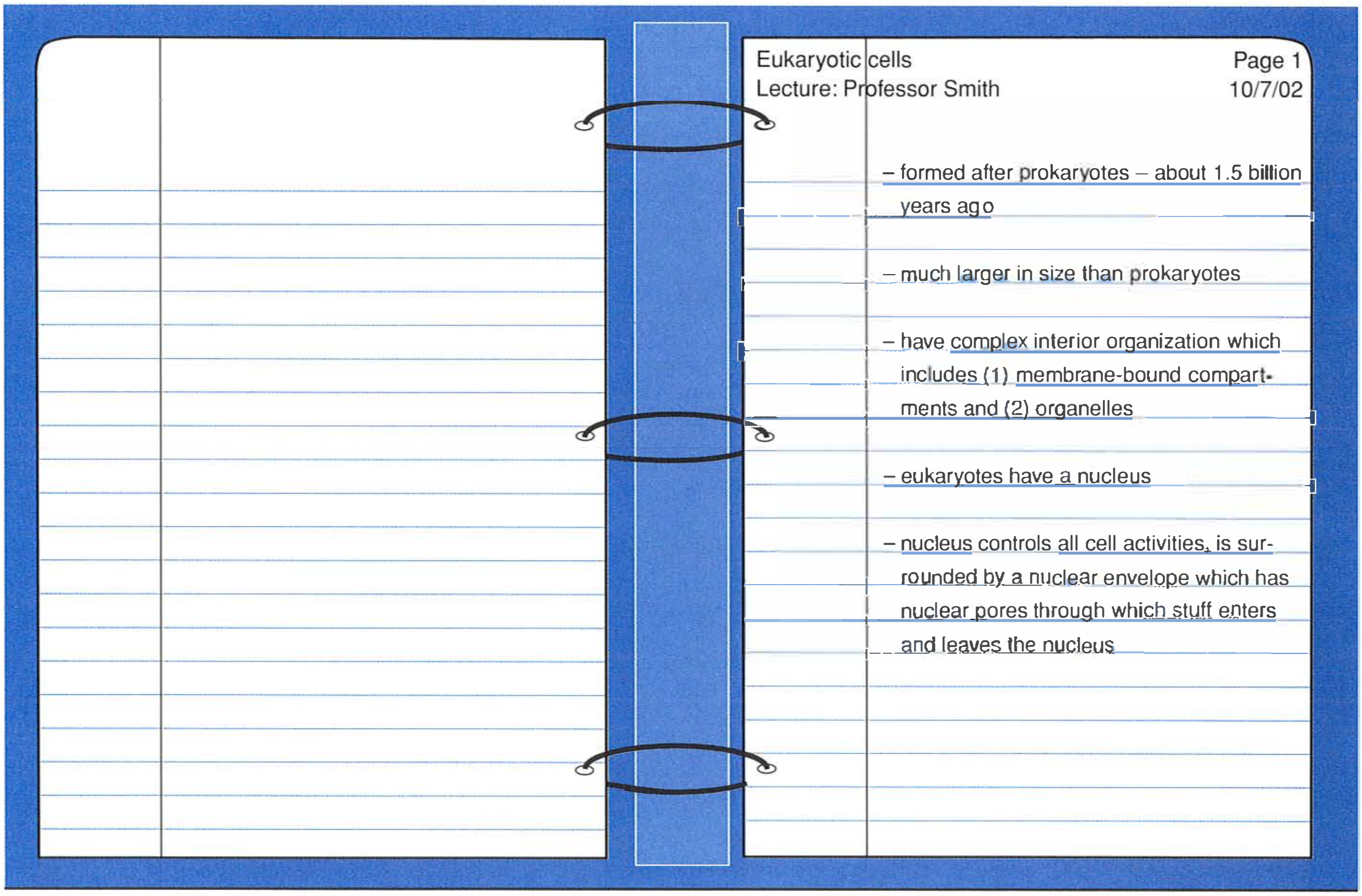
Step 2—Revising Notes after Class

Note revision is a process of reviewing and elaborating on notes taken in class. Ideally, note revision should take place one to twenty-four hours after the original notes were taken. Revision is a way of moving information from the notes into long-term memory for later retrieval. Research on memory has demonstrated the idea of a "retention curve": up to 75 percent of information "learned" can be forgotten within forty-eight hours (Bahrick 1984). Practicing note revision can substantially increase the retention of biology content.

Prominent Features of Revised Notes

(see Figure 3.8)

- The *main ideas* have been added to the left-hand column of the notes pages, and gaps in the details have been filled in the right-hand column (shaded portions)
- On the left-hand side of Figure 3.7 is what



Eukaryotic cells
Lecture: Professor Smith

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– formed after prokaryotes – about 1.5 billion years ago

– much larger in size than prokaryotes

– have complex interior organization which includes (1) membrane-bound compartments and (2) organelles

– eukaryotes have a nucleus

– nucleus controls all cell activities, is surrounded by a nuclear envelope which has nuclear pores through which stuff enters and leaves the nucleus

Figure 3.7. A sample of "unrevised" notes from a typical biology class

Landmark College calls the *sweat page*, recorded on the back of the previous page.

Sweat pages include the following:

— A variety of questions; some of these questions might be asked in class; others are reminders that the student needs to look up information

— Visual mnemonics of key terms or concepts (e.g., a student might draw a cell with no nucleus to represent a "prokaryote")

— A short summary of the lecture

What follows is a step-by-step guide to revising notes:

Take a complete set of notes. Within six to twenty-four hours, meet with a study partner

Pull out main ideas and write in left margin

Highlight main ideas and important vocabulary

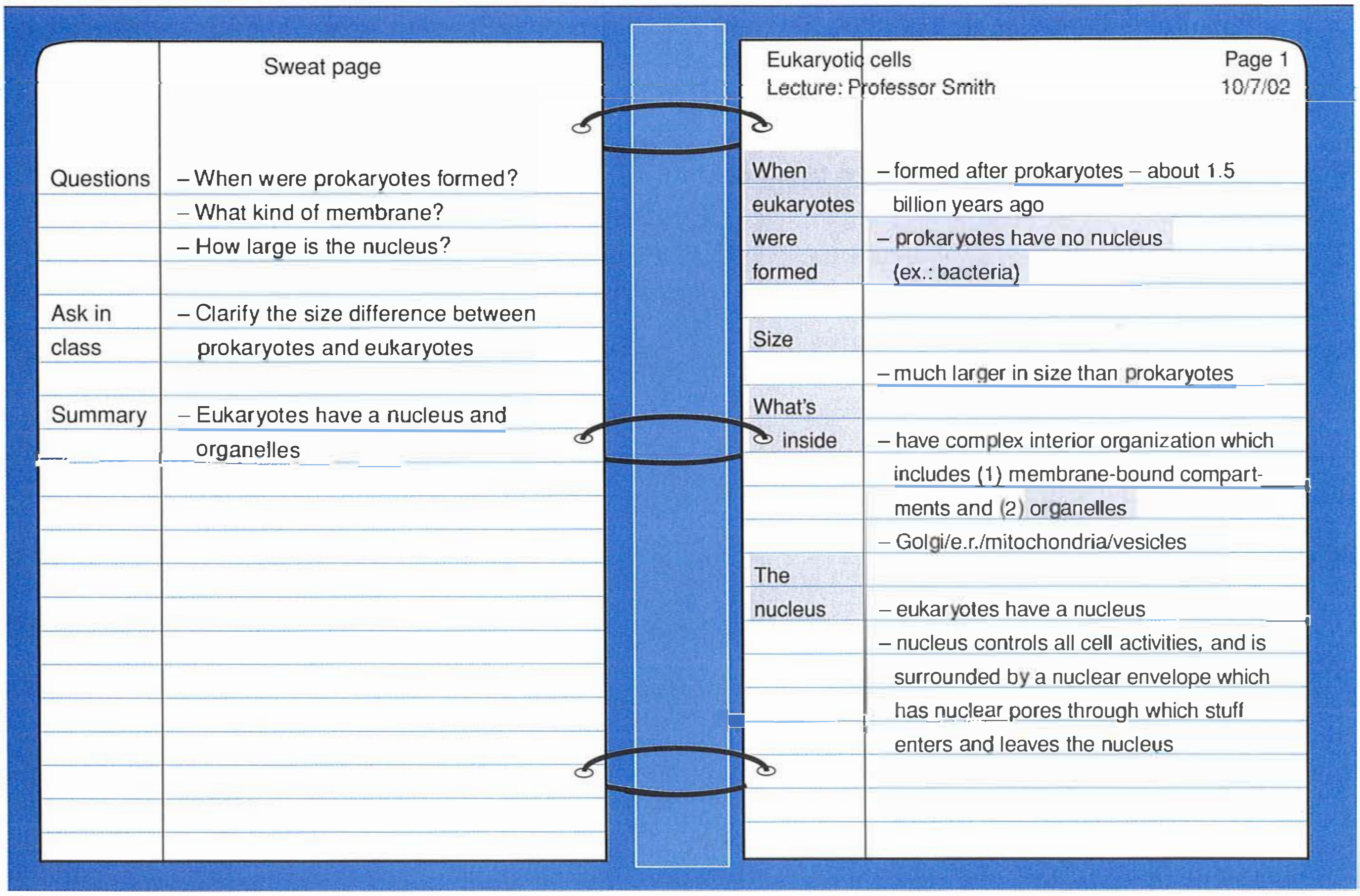
Compare notes; identify missing information and add

Ask questions (the sweat page)

Summarize notes at bottom of sweat page

Draw visuals and graphics to further elaborate notes

Self-test by covering one column and recalling information from the other



Sweat page

Questions	– When were prokaryotes formed? – What kind of membrane? – How large is the nucleus?
Ask in class	– Clarify the size difference between prokaryotes and eukaryotes
Summary	– Eukaryotes have a nucleus and organelles

Eukaryotic cells
Lecture: Professor Smith
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When eukaryotes were formed	– formed after prokaryotes – about 1.5 billion years ago – prokaryotes have no nucleus (ex.: bacteria)
Size	– much larger in size than prokaryotes
What's inside	– have complex interior organization which includes (1) membrane-bound compartments and (2) organelles – Golgi/e.r./mitochondria/vesicles
The nucleus	– eukaryotes have a nucleus – nucleus controls all cell activities, and is surrounded by a nuclear envelope which has nuclear pores through which stuff enters and leaves the nucleus

Figure 3.8. A sample of "revised" notes

Teaching the Master Notebook System

Because this system may be completely new for students, it is important to be explicit about how to set up and manage a master notebook. Here are some suggestions for effective implementation:

- Distribute a model master notebook at the beginning of the course with all pertinent sections, tabs, note examples, etc. Put one on reserve in a library or resource center.
- Directly teach how to take notes, and let students practice taking and revising notes according to the two-column system. Do this at the beginning of a course, and then build in the expectation that students will apply the technique for the rest of the course.
- Check notebooks and provide feedback on them, especially at the beginning of a course.
- Consider implementing a formal assessment of the notebook using a rubric. A sample master notebook assessment rubric can be found **on page 134**.

Electronic Versions of the Master Notebook

Some students may prefer to keep their master notebooks electronically on their laptop computers. For some students with poor visual/spatial skills who struggle to manage paper effectively, this can be a viable alternative. With some simple changes and guidelines, the system described above can be easily adapted to an electronic format.

Conclusion

Since organization and management of course materials are essential to succeeding in all academic courses, using the master notebook system can provide vital and effective support for all students in introductory biology courses.

References*

Bahrick, H. P. 1984. Semantic memory content in perspective. *Journal of Experimental Psychology* 11:1–29.

Pauk, W. 2000. *How to study in college.* 7th ed. Boston: Houghton Mifflin.

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* Landmark faculty members Christine Arieta, James Baucom, and Frank Klucken contributed their ideas, diagrams, and feedback to this section.

Teaching Study Skills: Textbooks

Background

Biology textbooks typically pose a great challenge to all students, but especially to students with learning disabilities. These dictionary-sized tomes hold a vast reservoir of descriptions of biological phenomena that can at first glance be quite overwhelming and off-putting. To a student with little background knowledge, the organization is obscure; most of the facts and descriptions of phenomena seem disconnected. It is hard to find the big picture or the unity of biology when so many details seem to be emphasized.

The vocabulary demands of a biology textbook can be viewed as another intimidating factor. Learning biological terminology is like learning a foreign language. Not only are there lots of Latin-based words, but these words are often introduced at a rapid-fire pace.

That biology textbooks lack user-friendliness has not gone unnoticed. The American Association for the Advancement of Science, through its Project 2061 initiative (AAAS 2000), has released a scathing assessment of science textbook quality. Its criticism includes some of the most popular texts of biology at the high school level. The goal of Project 2061 is to improve science literacy through research-based reforms. According to AAAS's assessment, the texts neither aligned well with the National Research Council's (1996) National Science Education Standards, nor did they promote meaningful scientific literacy.

The Project 2061 guidelines advocate science textbook reform that follows these principles:

- Explicit inclusion of common student misconceptions about science
- Structured exercises that promote thinking about scientific phenomena
- Lots of opportunities for students to practice and apply what they are learning

While we wait for these reforms to become reality, textbooks will continue to be a key component of our science teaching culture. Biology teachers must recognize the inherent challenges these texts offer students, and provide direct support and structures that make managing and learning from a biology textbook easier (Roseman, Kulm, and Shuttleworth 2001).

Strategies and Ideas

Choose the Right Book

There are myriad choices for biology textbooks at both the high school and the college level. Besides the criteria put forward under Project 2061, consider using a text that has these features, which are beneficial to students with learning disabilities:

- Is concise, not a compendium
- Is driven by concepts, not terms and details
- Provides a sense of the big picture and often refers to it
- Offers a visually appealing but not overwhelming or overstimulating layout
- Contains effective learning aids, such as chapter outlines and headings in the form of questions
- Has a CD-ROM supplement for the computer-oriented learner
- Contains quality visual aids to help visual learners
- Provides a user-friendly glossary with easy-to-understand definitions

Host a Textbook Orientation Session

Because some students have difficulty sensing and interpreting textbook structure independently, spend some time in class before assigning reading from the book to preview the features and layout of the text. Choose a sample chapter and uncover the structure and learning aids explicitly with students. This can be more informal with a savvy group of students, or more structured with a less sophisticated group. **See page 61** for an example of a biology textbook orientation guide.

Provide Clear and Explicit Expectations for Student Use of Text

Present to students a written set of instructions on your text-reading expectations. For example, you may decide that the SQ3R reading technique (**see page 59**) is the approach that will work best. Or you may come up with some variation on that. The important thing is to offer guidance to students and set a standard for their efforts.

Make Individual Suggestions to Students

Although tailoring your teaching may be hard as a course begins, use what you know about your students' learning profiles to make suggestions to individual students. For example, an instructor might suggest to a strong visual learner that he or she focus learning on the diagrams and other visual aids contained in the text and use the reading as a backup. As another example, an instructor might recommend that a student take class notes directly in the textbook next to the relevant section. This may help that student interact more effectively with the text, noting its structure and relevance to the course.

Use the Text During Class

The more you emphasize and make reference to the text, the more value (and therefore use) your students will place on it. This can be done in two ways. First, use the anecdotes, examples, and visual diagrams from the text during your in-class lessons; doing so may help to bring the book alive for students. Second, have open-ended discussions about students' experiences with the text. Ask students to reflect on and share their comprehension and study strategies, and encourage them to offer criticisms of the text.

Provide Instruction on a Reading Technique

Instruction and guidance on specific reading techniques may assist students in using biology textbooks more effectively. One common and effective example is called *SQ3R*, developed by psychologist Francis P. Robinson (1946). In a nutshell, it combines reading with active note taking and review, and is an example of what is called a *multipass* strategy. The following provides an overview of SQ3R:

S = Survey
Q = Question
R = Read
R = Recite
R = Review

Survey — A survey entails a before-reading preview of an assignment that focuses on looking over headings, introductory outlines, visual aids, and chapter summaries. This helps readers anticipate upcoming content and helps make a connection to their prior knowledge.

Question — For texts whose headings are not in the form of questions, the reader creates and writes questions next to the major chapter headings. This helps to foster purpose and a sense of actively searching for the answers within the reading.

Read — Reading is driven by the need to search out answers to the questions the reader has written. Answers are highlighted, as are other ideas that seem key. A color-coded highlight system is used that is consistent from reading to reading: one color for main ideas, one color for important details, and one color for vocabulary. The 20 percent rule is used: no more than 20 percent of text should be highlighted. Another way to express this is: highlight only two lines out of every ten lines of text.

Recite — Highlighting is reviewed, and notes that paraphrase main ideas and vocabulary are written in the margin. Symbols and abbreviations are used to note things such as questions (?), most important concepts (*), and connections between concepts (arrows).

Review — The completed reading is looked over, learning is verbally reviewed, comprehension level is assessed, and some self-quizzing techniques are carried out.

For a fuller explanation of this technique, examine the following online resource:

http://www.ucc.vt.edu/lynch/TextbookReading.htm

Give Out a Set of Study Questions for Each Text Chapter

The teacher can develop study questions or can use the ones commonly provided at the end of each chapter in the text. If using the questions provided by the text, photocopy them so students have a handy reference guide while reading that does not require them to turn pages to the end of the chapter. Identify the questions that are most relevant and those which are unimportant in your course. For students who need extra support, provide the page number reference for each study question. This technique gives students a clear sense of what knowledge they are accountable for in each reading assignment. The following are examples of study questions for a textbook chapter on evolution:

a. Explain the central tenet for the theory of evolution.
b. Distinguish between Darwin's theory of natural selection and a broader theory of evolution.
c. Paraphrase the observations and inferences that form Darwin's theory of natural selection.

Provide a Graphic Organizer for Text Note Taking for Each Chapter

A graphic organizer should show a visual outline that is partially filled in with headings or ideas. The rest is left blank for the students to fill in while they are reading. **See page 64** for a sample graphic organizer for a biology textbook chapter. The instructor may need to model how to best incorporate this tool, after which students can practice designing their own graphic organizers for reading notes. The Inspiration software program is an excellent tool for creating graphic organizers. Consider teaching it to students and letting them apply it to their reading. This kind of task is also a good introduction to more formalized concept maps.

Assign a Reading after a Class Session Has Introduced the Concepts

Some students may make stronger connections to the reading if their first exposure to ideas and concepts is in class with concrete phenomena or examples. Suggest using the text as a review or elaboration of class notes and activities. This technique supports the idea that an initial hands-on and direct experience with concepts can provide a foundation for more effective reading-based learning later.

Build Metacognition into the Textbook Reading Experience

After students have been working in the course for a while, ask them to reflect on their effectiveness using the textbook. What reading strategies and techniques have they been using? Are they working? What might they change in their approach to get more out of the textbook? Encourage them to share their experiences and develop a personalized process for interacting with their textbook.

Conclusion

It is important to guide students through effective textbook usage. Instructors can choose from the strategies described above to make biology textbooks more meaningful to all students.

References

American Association for the Advancement of Science (AAAS). 2000. *Big biology books fail to convey big ideas, reports AAAS's Project 2061*. News release, June 27, 2000. http://www.project2061.org/press/pr000627.htm

National Research Council. 1996. *National science education standards*. Washington, DC: National Academies Press.

Robinson, F. P. 1946. *Effective study*. New York: Harper and Bros.

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BIOLOGY TEXTBOOK ORIENTATION GUIDE

Directions: Analyze the course textbook, looking for the features listed below.

1. The Textbook as a Whole

Check if present:

___ Brief table of contents

___ Detailed table of contents

___ Introduction

___ Glossary

___ Index

Are there any appendices? If so, what are they?

2. A Sample Chapter

Choose any chapter, ideally in the middle of the book, and look for the following features. Write your answer in the space below each question.

Chapter Beginning

Does the chapter start with an outline?

Does the chapter start with a key concept list?

Does the chapter start with questions to focus reading?

Does the chapter start with a story to grab interest?

Describe any other learning aid or feature evident at the beginning of the chapter.

Within the Chapter

How many different-size headings are there?

Are there different-size headings in different colors?

Are the headings in question form or statement form?

Are there number codes for each heading or section?

Is vocabulary in bold or italics?

Is some text in color? If so, how is color used to mark different kinds of text?

Are there summaries after each major topic or heading?

Are visual aids varied, simple, and clear?

Are there boxed sidebars? If so, what is their purpose?

Are other learning aids or features evident? If so, what are they?

Chapter Ending

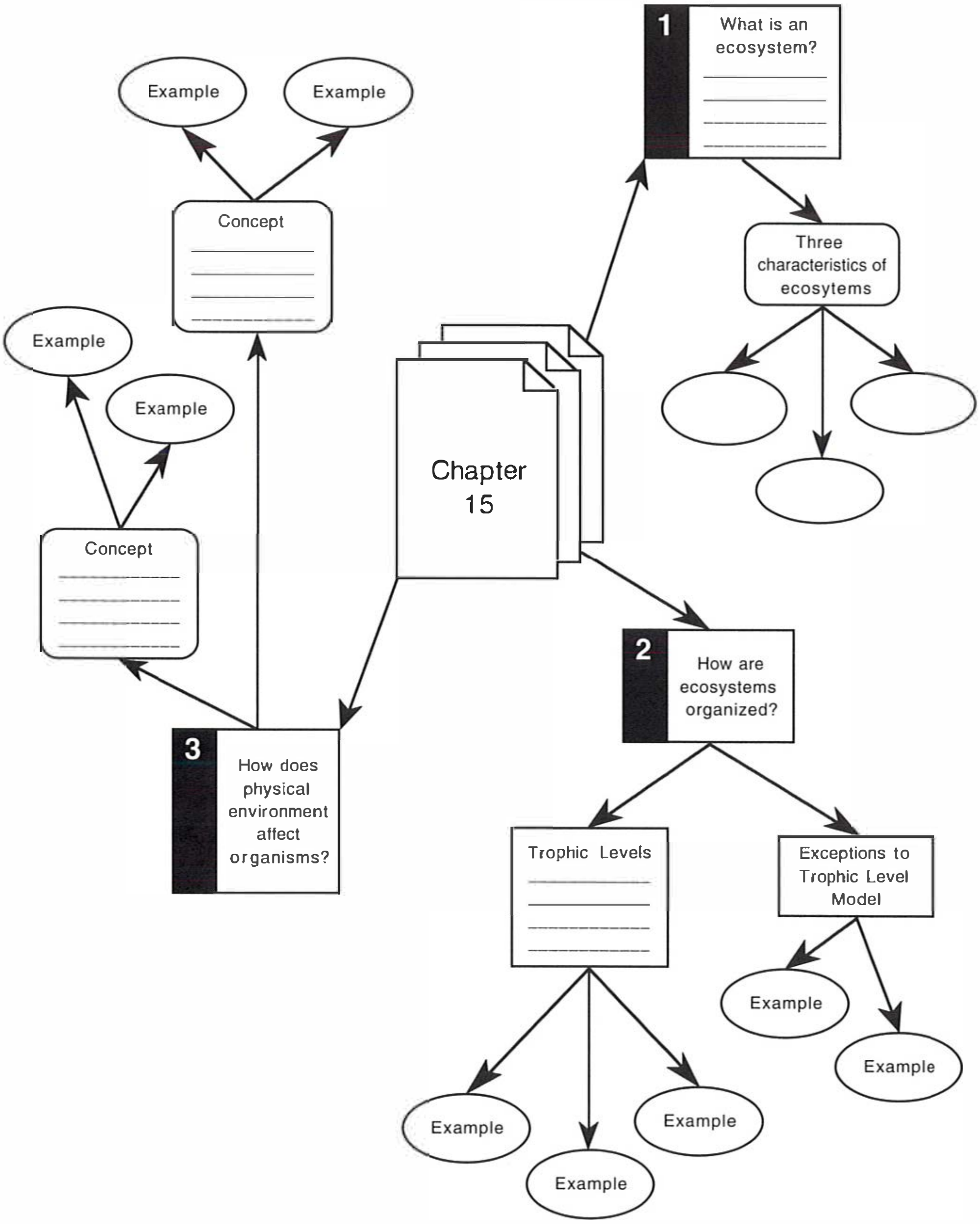
Is there a chapter summary or outline of key concepts?

Is there a vocabulary list? With page references?

Are there review questions? If so, what form do they take? (multiple choice, short answer, etc.)

Are there any other learning aids or features evident? If so, what are they?

SAMPLE GRAPHIC ORGANIZER FOR A TEXT ASSIGNMENT



Teaching Study Skills: Vocabulary

Background

There is no way out of it: learning biology means learning a unique vocabulary. Biology instructors hear all the time that students dislike science because of the vocabulary challenges. What students remember most about their past biology course experiences is encountering new vocabulary words and then being asked to regurgitate them during testing. In a particular textbook for introductory college biology courses, for example, skimming three pages at the beginning of a chapter revealed sixteen boldfaced terms introduced and defined. Many of these terms were then used over and over to explain and relate to the others. And this does not include biology-specific vocabulary that was introduced in previous chapters.

Clearly, the volume of term introduction can be overwhelming, especially to a student with a language-based learning disability. While it is up to each individual instructor to choose the volume and pace of new vocabulary introduction, there are some things that can be done to make vocabulary acquisition less of a barrier and a turn-off for all students in introductory biology.

Strategies

Provide Concrete Experiences with Vocabulary Words

Providing direct experience with the concepts behind new vocabulary words before language tags are associated with the phenomena helps learners more readily understand new terms once they're introduced. The mental schema created by the direct experience will make the transfer to linguistic and conceptual understanding easier. For example, before introducing the term "osmosis," set up a demonstration that shows it. Let the students observe it, experience it, and think about it before they have a name for it. Introduce the name after the demonstration. While this may be difficult for many vocabulary words—"gene," for instance—other terms, with a little creativity, lend themselves well to this strategy.

List the Essential Vocabulary for Each Unit or Chapter

Provide a handout at the beginning of a chapter or unit that lists the key vocabulary words students will be accountable for. An instructor may choose to reduce (or add to) the vocabulary that the textbook includes as boldfaced or as a study aid at chapter's end. This simple task will make it clear to students what they should spend their study time focusing on.

Chunk Vocabulary

When designing the handout of key vocabulary described in the previous paragraph, consider grouping, or "chunking," the words into related terms or "semantic clusters." **See page 68** for an example of a chunked vocabulary list.

Chunking is a more effective way to develop vocabulary than isolating individual words and their meanings, because related words reinforce each other when learned together. Chunking encourages students to think about terms and concepts as associated and related, rather than as discrete, unrelated information. Eventually, after some practice, students can be assigned to chunk a vocabulary list independently. This may be a good activity for helping students transition toward making concept maps.

Teach Word Roots for Terms

Provide students with a list of word roots, prefixes, and suffixes commonly used in biology. Have them store the list in a prominent place, and make explicit references to it in class when a new term is introduced whose roots are on the list. **See page 69** for a list of biology word roots.

When writing a term down for class viewing, analyze the word's parts, if appropriate, with the students. Make this a regular feature of your teaching. However, be warned that a generic list of scientific roots, prefixes, and suffixes may prove to be too lengthy and therefore overwhelming to students. Consider developing and providing a course-specific, instructor-generated list as an alternative. Try to keep it short enough to fit on two sides of a single sheet.

Suggest the Strategic Use of Vocabulary Flash Cards

Instead of just asking students to make vocabulary flash cards, suggest the following specific method of doing so and give out a model:

- On one side of a card (4" x 6" is preferable), write the vocabulary word in color. (If using the chunking system, all words of the same color would be in the same chunk.)
- On the opposite side, do three things: (1) write a definition (paraphrased is best), (2) draw a visual that illustrates the word, and (3) write a personal experience, association, or connection with the word.

This system allows for a diversity of learning styles. **See page 74** for an example of a flash card.

An alternative approach, especially helpful for test formats that contain a matching or vocabulary recognition component, would be to write vocabulary words on one card and their definitions on another card. Students can then simulate the matching and recognition on their own in preparation for a test.

Vocabulary Presentations

Hold in-class student-led vocabulary presentations. For example, assign each student a word from the unit of study. Have each prepare a short presentation, according to specific guidelines given by the instructor, and present the word to the class. Encourage students to be creative by acting out their terms or by providing concrete or symbolic illustrations of the terms.

Mnemonics

Education researchers Mastropieri and Scruggs (1998) have shown the usefulness of mnemonic memory strategies for vocabulary acquisition with a diversity of learners. Using a mnemonic strategy provides a student with some form of mental cuing structure that facilitates recall of detailed, long, or complex information. Mastropieri and Scruggs's research has shown that student-created mnemonics are more effective than teacher-made mnemonics.

If student recall of vocabulary is an important part of an instructor's assessment of science learning, then teaching students some basic mnemonic strategies is suggested. Below are three basic kinds of mnemonic devices: the acronym technique, the keyword technique, and the "Pictionary" technique, with some biology-related examples.

Acronym technique. A student or instructor uses the terms to be memorized to create a word or sentence in a precise sequence. If a student had to recall the phases of mitosis in sequence, for example, the acronym "PMAT" might help. Since that acronym is not a word itself and therefore may be hard to remember, the sentence "**P**runes **M**ake **A**pples **T**art" may work better.

Keyword technique. Term recall is facilitated by identifying words or phrases that are acoustically similar to the term to be remembered. For example, if the term "mitochondria" needs to be recalled, then the mnemonic "the mighty have lots of energy" may assist in summoning that term and its function from a student's memory.

"Pictionary" technique. Term recall is facilitated by the creation of a concrete or a metaphorical image. For example, if the term "endoplasmic reticulum" needs to be recalled, then the drawn or imagined image of an ambulance traveling on a road to the **E**mergency **R**oom may assist a student in remembering the desired term and its function.

It can be both fun and valuable for students to share their mnemonic creations with the rest of the class.

Build Metacognition into Vocabulary Development

After students have been working in the course for a while, ask them to reflect on their success with learning course vocabulary. What vocabulary learning strategies and techniques have they been using? Are these strategies working? Are there other techniques they could use that might be more effective given their learning styles? Encourage them to share their experience and develop a personalized process for building course-specific biology vocabulary.

Reference

Mastropieri, M. A., and T. E. Scruggs. 1998. Enhancing school success with mnemonic strategies. *Intervention in School and Clinic* 33 (4): 201–208.

EXAMPLE OF A“CHUNKED” VOCABULARY LIST FOR AN ECOLOGY UNIT

Plants

- autotroph
- producer
- photosynthesis
- carbohydrates
- cellulose

Heterotroph Feeding Strategies

- herbivore
- carnivore
- omnivore
- scavenger
- decomposer
- detritivore

Feeding Relationships in Ecosystems

- primary consumer
- secondary consumer
- tertiary consumer
- food chain
- food web
- trophic level
- rule of 10

Nutrient Cycling

- hydrological cycle
- carbon cycle:
  - greenhouse effect
  - greenhouse gases
  - global warming
- nitrogen cycle:
  - nitrification
  - nitrogen fixation
  - ammonification

Energy Concepts

- energy
- chemical energy
- chemical bonds
- entropy
- first law of thermodynamics
- second law of thermodynamics
- cellular respiration

BIOLOGY VOCABULARY: WORD ROOTS

Knowing the common roots, prefixes, and suffixes involved in forming many words will help students understand and retain terms we often use in biology. Many components are derived from Latin (L) or Greek (G), but other languages also contribute. (Students already know a fair number of roots, whether they realize it or not, as the same roots form many ordinary words in the English language.) This brief list is compiled mainly from the *Dictionary of Word Roots and Combining Forms* by Donald J. Borror (Mountain View, CA: Mayfield Publishing Co., 1960), *The New Cold Latin and English Dictionary* (New York: Bantam Books, 1966), and *Webster's Ninth New Collegiate Dictionary* (Springfield, MA: Merriam-Webster, 1989). (Note: Variations of given roots are preceded by -; for example, *albi* and *albid* are variations of the given root *alb*.)

Root	Meaning
ab	(L) off, from, away
ad	(L) to, toward
alb, -i, -id	(L) white
allelo	(G) one another; parallel
ameb, -a, -o	(G) change
amph, -i, -o	(G) around, on both sides; double
ampulla	(L) a flask
an	(G) without, not
ang, -ea, -i, -io	(G) a vessel, box, case
annel, -us	(L) a ring, a little ring
ante	(L) before
archae, -o	(G) ancient
arthr, -o, -um	(G) a joint; speech
aur, -ar, -at, -e, -i	(L) gold, golden
aur, -i, -icul, -is, -it	(L) an ear
aut, -o	(G) self
bi	(L) two, twice, double
blast, -em, -o, -us	(G) a bud, sprout
botan, -a	(G) pasture, grass, fodder
branch, -i, -o, -ium	(G) a gill; a fin; hoarse

Root	Meaning
caec	(L) blind
calc, -i	(L) the heel; lime, limestone
cent, -en, -i	(L) a hundred
cephal, -a, -o	(G) the head
chondr, -o, -us	(G) cartilage; grain
chrom, -ato, -o, -a	(G) color
cili, -a, -o, -um	(L) an eyelid, eyelash, small hair
circum	(L) around
co, -l, -m, -n	(L) with, together
cyt, -e, -o, -us	(G) a hollow place; the cell
de	(L) from, down, out
deca	(G) ten
decim	(L) one tenth; ten
derm, -a, -ato, -o	(G) skin
deutero	(G) the second
dext, -er, -r, -ro	(L) the right-hand side; clever
dich, -o	(G) two, in two
dipl, -o	(G) double, two
echin, -o, -us	(G) hedgehog; sea urchin
eco	(G) a house, abode
ect, -o	(G) outside, out, outer
of	(L) out, from, away
epi	(G) upon, over, beside
eu	(G) good, well; true
fasci, -a	(L) a bundle; a band
fenestr, -a	(L) a window
foss, -a	(L) a ditch, trench
gam, -o, -us	(G) marriage
gast, -ero, -r, -ro, -er	(G) the stomach, belly
gen	(G) to bear, produce;
	(L) a nation, race
gene, -sis	(G) origin, birth
gnath, -o, -us	(G) the jaw

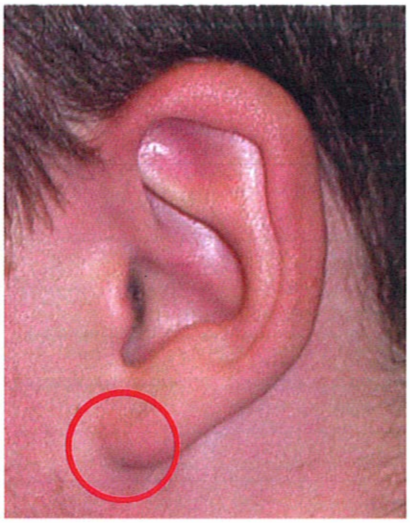
Root	Meaning
gymn, -o	(G) naked, bare
haem, -ato, -o, -a	(G) blood
heli, -a, -o	(G) the sun
helmin, -s, -th	(G) a worm
heter, -o	(G) other, different
hom, -in, -o	(L) man
hom, -eo, -o, -oeo, -oio	(G) like, same, alike
homin, -i	(L) man
hormon	(G) excite
hydr, -a, -i, -o	(G) water
hyp, -o	(G) under, beneath
hyper	(G) over, above, excessive
ichthy, -o, -s	(G) a fish
id	(L) a condition of
in	(L) in, into; not, without; on
infra	(L) below, beneath
is, -o	(G) equal
kary, -o	(G) nut; the nucleus
kera, -to	(G) horn
kilo	(G) a thousand
lact, -e, -i, -o	(L) milk
lamin, -a, -i	(L) a thin plate, sheet, layer
leuk, -o	(G) white
lys, -i, -is, -io	(G) loose; a loosening
mar, -i	(L) the sea
mei, -o	(G) less; to diminish
melan, -o	(G) black
mes, -o	(G) the middle
micr, -o	(G) small
mit, -o, -us	(G) a thread
morph, -o, -a	(G) form
morul, -a	(L) a little mulberry
muta	(L) change

Root	Meaning
nem, -a, -ato, -o	(G) a thread
neur, -a, -o	(G) a nerve, sinew, cord
ob	(L) reversed, against
olig, -o	(G) few, scant, small
-ology	(G) the science of
oo	(G) an egg
opercul, -um	(L) a cover, lid
ora	(L) mouth
orni, -th, -tho, -s	(G) a bird
oss, -e, -i	(L) a bone
ov, -i, -um	(L) an egg
pack, -y	(G) thick
par	(L) bear, give birth to
par, -a	(G) beside; beyond, near
par, -i	(L) equal; a titmouse
partur, -i	(L) bring forth young, give birth to
pect, -in, -o	(L) a comb
pect, -o	(G) fixed, congealed
pect, -or, -us	(L) the breast
ped, -a, -e, -i, -o	(L) a foot;
	(G) a child; the earth; letter; an oar
per	(L) through, by means of
perl	(G) around
phag, -e, -o	(G) eat
pheno	(G) show, seem, appear; purple-red
phil, -a, -i, -o	(G) love, loving
phos, phot, -o, -a, -i	(G) light, radiant energy
phyll, -o, -um	(G) a leaf
phyt, -o, -um	(G) plant
pinn, -a, -i	(L) a feather; a wing
plac, -o	(G) a tablet, plate; flat
plankt, -o	(G) wandering

Root	Meaning
plast, -o	(G) formed, molded; counterfeit
plat, -e, -i, -y	(G) broad, flat
pneuma, -ti, -to	(G) wind, air, breath
pneumo, -n, -no	(G) the lungs
pod, -o, -y	(G) a foot
poikil, -o	(G) varied; variegated
pro	(G) before, in front of, forward; instead of, for
prat, -e, -o	(G) first, orginal
pseud, -o	(G) false
quali	(L) what kind
quant	(L) how much
re	(L) back, again
retr, -o	(L) back, behind, backward
rhiz, -a, -o	(G) a root
sal, -i	(L) salt
sarc, -i, -o	(G) flesh
scal, -ari, -i, -a	(L) a ladder
soma, -t, -to	(G) a body
spor, -a, -i, -o	(G) a seed
stom, -a, -ato,-o	(G) a mouth
sub	(L) under, below
succ, -us	(L) juice, sap
super	(L) above, over
sym	(G) with, together
thigm, -a, -ato, -o	(G) a touch
trop, -ae, -e, -o	(G) to turn, change
troph, -i, -o	(G) nourish; food, nourishment
-ul, -a, -um, -us, -e	(L) little
vas, -a, -o	(L) a vessel, duct
viv, -a, -i	(L) alive, living
zo, -a, -i, -o, -on	(G) an animal

FLASH CARD EXAMPLE

Recessive



- A gene whose expression can be masked when paired with a dominant version
- Represented by small letters
- rr dd gg
- Must always be homozygous to be expressed
- I have attached ear lobes—a *recessive* trait!

Teaching Study Skills: Assistive Technology

COMPREHENSION AND generation of written language are necessary for student success in academically rigorous courses such as biology. This can be problematic for students with learning differences who may be weak in basic reading, writing, and communication skills. Assistive technology offers these students access to books, writing, and critical thinking about a world of concepts that are otherwise inaccessible to them, and thereby helps them achieve their educational goals. This technology includes tools such as word processors, screen readers, voice recognition software, visual mapping software, and presentation software. Successful integration of this technology into introductory biology courses is dependent upon matching students with appropriate hardware and software based on individual needs, coupled with explicit instruction on how to use the assisstive technology.

What Keeps Students from Succeeding?

In the past thirty years, research has emerged that describes the most common difficulties that students face in school. They are the following:

- Difficulty decoding text
- Slow processing of text
- Poor comprehension of written text
- Difficulty encoding (spelling)
- Poor handwriting
- Difficulty organizing ideas
- Difficulty paying attention
- Difficulty completing assigned work

While this list is by no means comprehensive, it covers the most common reasons why students fail in school. Although remedial strategies can be highly effective for many of these difficulties, students often continue to struggle with them. Such students are severely handicapped in their ability to achieve the goals of a secondary and post-secondary curriculum.

Landmark College, along with other leading educational institutions, such as the University of Oregon's Center for Computer-Based Study Skills (Anderson-Inman, Knox-Quinn, and Szymanski 1999), has developed technology strategies that address the learning issues that commonly prevent students from achieving their learning potential. With these strategies available as tools to our students, instructors and students are able to choose software strategies that will reduce or eliminate the barriers to learning. These tools not only are effective for students with learning difficulties but are sound pedagogical practices for the entire range of diverse learners.

What Technology Applications Are Useful?

The technology applications to assist students in learning academic skills are numerous, but they fall into some basic categories:

Word Processors

Word processors are not typically thought of as assistive technology, but at their most basic level, they assist students with graphomotor difficulties to write without relying on handwriting. They also provide students with assistance in spelling (spell checker) and grammar (grammar check). Word processors commonly have tools for editing and revising written drafts, which are of great assistance to students who struggle with proofreading and paper revision.

Screen Readers

A text-to-speech screen reader converts computer-based text into spoken words. It also allows slow or inaccurate readers to efficiently process text-based information aurally and visually. Screen readers vary widely, from the most bare-bones, which do nothing more than read the text, to the highly sophisticated, which include features for highlighting, note taking, and customizing the entire reading experience. Text-to-speech screen readers assist students with difficulties decoding written text, those who have difficulty reading fluently, and those who have trouble paying attention to what they read (Hecker et al. 2002; Fein 2002). Typically, a biology textbook or handouts from teachers will have to be scanned and converted into digital format before the screen reader can assist the student. Since biology texts are often dense with visual aids such as pictures, charts, and maps, it's important to have a scanning system with an Optical Character Recognition (OCR) system that can handle pages of mixed text and graphics. Ideally, teachers or a school-based resource center would help students with this preparatory stage, so students can utilize their study time for actually reading and understanding their texts.

Voice Recognition

Voice recognition software is good for students who have difficulty converting their thoughts into written words. Students must train the software to recognize their voices; accuracy rates run around 95%. While these software programs are greatly improved over their early versions, students with thick accents or speech impediments still find them difficult to use. In addition, students must still rely on a good writing process in order to edit, revise, and proofread their essays.

Visual Mapping

Visual mapping software provides a link between teaching content and supporting thinking processes. Talking and writing out ideas are only one way of representing thinking. Students who have difficulty expressing thoughts in writing may find that visual mapping of concepts frees them from the limitations of their working memory, as well as from the limitations of syntax and spelling (Anderson-Inman and Ditson 1999).

Presentation Software

Presentation software such as PowerPoint is widely accepted as an effective means of communicating information because of its ability to combine graphics and text. It reduces the need for text, and it allows for ideas to be organized in outline form.

How Do You Decide What Technology Will Suit Which Student?

Assistive technology is effective only if the device or software builds on the strengths of the students who use it. There are a number of approaches, both formal—such as the *Functional Evaluation for Assistive Technology,* or *FEAT* (Raskind and Bryant 2002)—and informal, to assessing students for assistive technology tools; but any assessment must fit the assistive technology to the student and not vice versa. The key to a successful match between students and technology is to establish specific goals that hardware and software will enable a student to realistically achieve. Here are the key considerations for matching a student with an assistive technology tool:

- What is the student's diagnosis?
  — How severe is the disability?
- What are the student's learning strengths?
- What is the student's preferred learning style?
- How does the student's disability affect academic performance (reading, written language, math, study skills, memory, organization)?
- What are the requirements of the student's academic program?
- Where will the student need to use the assistive technology device (lecture, seminar, laboratory)?
- How comfortable is the student with using technology?

The best accommodation for a student is not necessarily the most high-tech one. The best assistive technology plans are those that take into account students' abilities, preferences, and the academic tasks that are required in their coursework (Bisagno and Haven 2002).

Setting the Stage for Success

Before students get the benefits of assistive technology, they must learn to interact with their computers. Some attention to how students touch and perceive their computers may make the difference between their acceptance or rejection of technology. Simple adjustments, such as reducing visual clutter on the desktop and placing shortcuts on the desktop to reduce the steps required to access programs and files, can greatly reduce confusion for students.

Teaching a system of file management is another crucial step for students with poor organizational skills, attention issues, or limited experience with technology. These students do well with a predesigned file/folder organizational structure, guidelines for accessing and housing their electronic files, and a regular weekly time in which to clean up their files.

Use Technology to Support an Established Learning Process

The key to successful teaching and learning is to break each skill into its component parts so that students understand the cognitive processes behind it. An example is writing, a skill that proves difficult for many students with learning disabilities. Learning to write successful essays, lab reports, and research papers requires that students approach the task as a process that includes generating and organizing ideas, drafting, editing, and revising. Despite the success that educators have had with teaching writing as a process, some students continue to have difficulty because of their language, attention, or executive function difficulties (Gander and Strothman 2001).

For students with writing difficulties, strategic use of software programs can bridge the gap between their writing needs and their writing abilities. Technology offers the chance for students whose potential was overlooked in the past to become successful writers. Following is a list of common barriers to writing success and the software that addresses them. **Also see page 79** for online assistive technology resources.

Poor spelling
- Spell checker, word prediction, voice recognition software

Difficulty expressing concepts in writing
- Voice recognition software

Difficulty with working memory
- Visual mapping software to reduce cognitive load
- Voice recognition software

Difficulty identifying relationships between concepts and time order
- Visual mapping software templates
- Word processor's templates

Poor planning strategies
- Visual mapping software for brainstorming and sorting
- Word processor's outline mode

Difficulty with reading
- Screen-reading software

Poor sentence structure
- Screen-reading software to find sentence errors or omissions

Poor attention to detail
- Word processor's "reviewing" toolbar for tracking errors and making changes

When assistive technology is used strategically throughout the writing process, it is not a bypass accommodation. Instead, it is an integral part of the process, allowing access to students who might otherwise be blocked from applying this important cognitive tool to achieve success in essay writing.

Conclusion

Assistive technology offers powerful tools to the many students with learning differences who would otherwise struggle with the academic demands of a biology course. Used strategically, and integrated into established pedagogical processes, assistive technology can lower the traditional barriers that have prevented so many students from achieving their educational goals and potential.

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* This chapter is adapted, with permission, from "The Use of Assistive Technology for College Students with ADHD," an article by Ellen Engstrom, M.A., Associate Professor at Landmark College, for the Children and Adults with Attention Deficit Hyperactivity Disorder (CHADD) newsletter, *ADHD Challenge* 17, no. 3 (2003): 5–6, 11.

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Gander, M., and S. W. Strothman. 2001. *Teaching writing to students with learning disabilities: A Landmark College guide*. Putney, VT: Landmark College.

Hecker, L., L. Burns, J. Elkind, K. Elkind, and L. Katz. 2002. Benefits of assistive reading software for students with attention disorders. *Annals of Dyslexia* 52: 243–72.

Raskind, M. H., and B. R. Bryant. 2002. *Functional evaluation for assistive technology*. Austin, TX: Psycho-Educational Services.

Assistive Technology Resources

Following is a list of Web sites for assistive technology information. Related products are shown in parentheses.

Text-to-Speech Resources

www.kurzweiledu.com (Kurzweil)
www.arkenstone.org (WYNN)
www.texthelp.com (Read & Write)
www.cast.org (eReader)
www.pixi.com/~reader1 (HELPread freeware)

Voice Recognition Resources

www.scansoft.com/naturallyspeaking (Dragon)
www.ibm.com/software/speech (IBM ViaVoice)
www.lhsl.com/voicexpress/ (Voice Express)
www.edc.org (general information)

General Information

www.cast.org
www.closingthegap.org
www.ldonline.org
www.ldresources.com
www.ala.org/roads (public libraries)
www.hood.edu/seri/serihome
www.snow.utoronto.ca/index/html
www.landmarkcollege.org/links.html
www.donjohnston.com (commercial link)
www.nextup.com/
www.freedomscientific.com (WYNN)
www.promo.net/pg (Project Gutenburg, a library of digital texts)

Using Varied Instructional Techniques: Multimodal Teaching

A MULTIMODAL TECHNIQUE is defined as a learning activity that includes the use of movement, tactile manipulation of materials, or a strong emphasis on color, drawing, or other graphic depictions of ideas. Most lab-based activities in biology are multimodal by nature. This chapter encourages teachers to use other kinds of hands-on techniques to support student learning. Using an assortment of multimodal techniques makes a biology class fun and interactive and acknowledges the diversity of learning preferences present in any class. Multimodal instruction can be an extremely effective technique to teach students key biological concepts.

Using Kinesthetic Role-Playing

In kinesthetic role-playing, students use their bodies, movement, and props to demonstrate how a biological concept works. One important application of kinesthetic role-playing is teaching biological processes, such as photosynthesis or cell respiration. But other concepts as well, such as exponential growth, can be taught or demonstrated through kinesthetic techniques. For a fully developed example of a kinesthetic role-play, see the "Cell Cycle Role-Play" activity **on page 269.**

Not only does using kinesthetic techniques recognize the value of the body as a tool to enhance conceptual learning; it also helps translate information that is linguistic and logical in nature to another medium that may be more effective for certain learners. (Howard Gardner has proposed the idea of multiple intelligences, including kinesthetic intelligence, in his book *Frames of Mind* [1993].) They are also particularly useful as a way to turn abstract information into a concrete form, thereby assisting students who are challenged by abstract thinking. In addition, students with attentional difficulties may stay more focused when engaged in kinesthetic activities. These techniques can provide an enjoyable break from the routine "seated" learning that characterizes many learning environments.

Using Tactile Manipulatives

"Manipulable" objects or materials can be used as tools to create or demonstrate biological content. For instance, students could be instructed to model the eukaryotic cell membrane by using styrofoam balls, pipe cleaners, marshmallows, and tape. The balls would represent the phospholipid heads, the pipe cleaners would represent the phospholipid tails, the marshmallows would represent the embedded proteins, and the tape would hold the model intact.

As another example, an instructor might ask students to construct a section of DNA using multicolored mini marshmallows and colored toothpicks. A suggestion might be to use four different-colored marshmallows for the bases, white for the deoxyribose, and a colored toothpick to represent the phosphate groups. Uncolored toothpicks could be used to represent hydrogen bonds between the bases. (It's also possible to give the students all

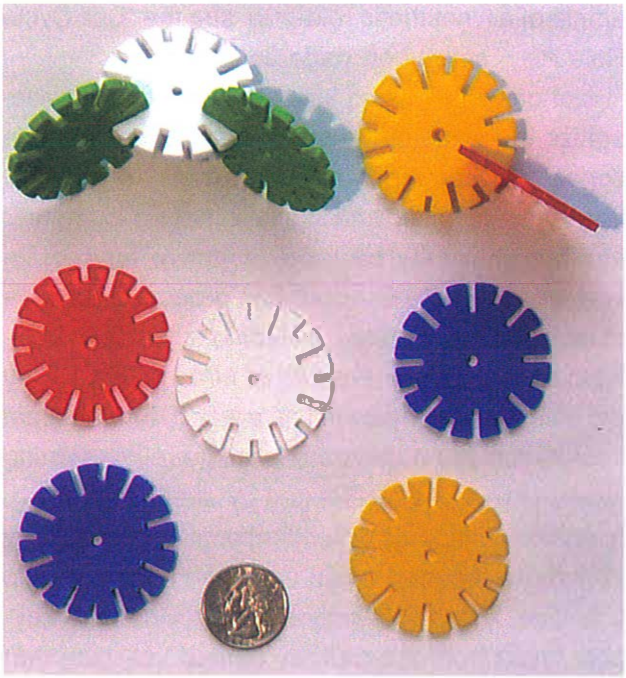

Figure 3.9. An example of a manipulative: FiddleDiscs

Figure 3.10. An example of a manipulative: Cuisenaire Rods

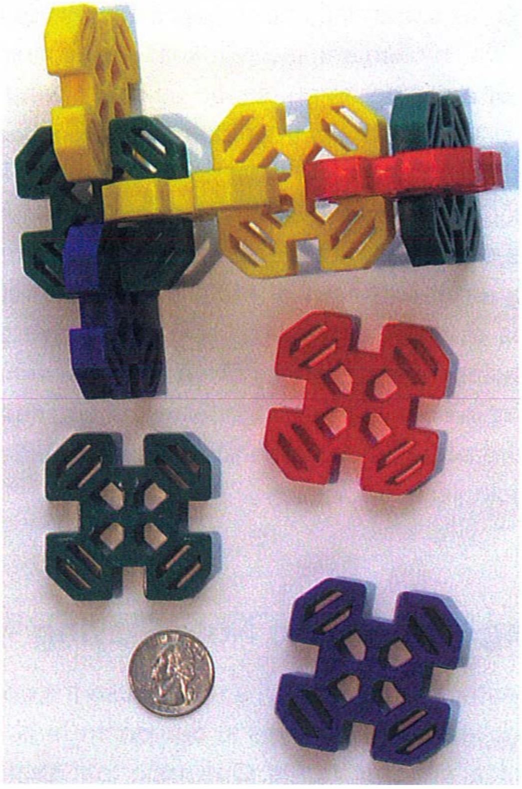

Figure 3.11. An example of a manipulative: Klondikers

the materials and let them decide how to use them.) This produces a model that is flexible and that can then be used to simulate replication.

See page 299 for a fully developed example of a tactile/manipulative–based activity called "Mendelian Genetics."

Similarly to kinesthetic role-playing, using tactile techniques engages the body in order to engage the mind. Abstract details about structures become concrete and colorful. **See the sidebar** for a list of useful materials that offer a range of manipulative applications.

USEFUL MANIPULATIVES FOR BIOLOGICAL CONCEPTS

- Legos
- Tinkertoys
- Klondikers
- Clay or Fimo
- Connex
- FiddleDiscs
- Bendies
- Atomic model kits
- Colored pipe cleaners
- Modeling clay
- Stockmar Brand Modeling Wax (less messy than modeling clay)

Using Large-Scale Drawing

This technique allows students to use large-motor activity to create drawings and diagrams. For example, the use of colored chalk on a large, rough surface, such as a sidewalk or parking lot, provides a tactile and kinesthetic experience. It also capitalizes on the use of color to distinguish structures or processes. This technique works best as a reinforcement or review exercise after some biological content has already been introduced. It requires that the class have reasonable access to a usable sidewalk area or parking lot that is safe and spacious. For those classes without easy access to a public sidewalk, another variation is to use large sheets of butcher paper and magic markers to create the drawings or diagrams. When adapting this technique, however, it's important to note that the large scale of this activity is key to its effectiveness. This technique is best suited for kinesthetic and visual learners.

For instance, students could be asked to construct a Venn diagram that shows the similarities and differences between meiosis and mitosis. Specific guidelines such as size, labeling, and time frame would be supplied by the instructor. Individual students or student teams could work on the same task or on different tasks, and could be asked to share and compare their work as part of the exercise. To add to the activity, students could also be asked to entertain questions from nonclass members passing by the chalking area.

Conclusion

The incorporation of kinesthetic techniques, manipulatives, and large-scale drawing into the biology classroom is relatively easy to accomplish and will improve the understanding of conceptual material. These multimodal strategies may also help those students with attention deficits to maintain their focus.

Reference

Gardner, H. 1993. *Frames of mind.* New York: Basic Books.

Using Varied Instructional Techniques: Graphic Organizers

What Are Graphic Organizers?

A *graphic organizer* is a teaching and learning tool that integrates both text and visual symbols (Hutcheson 2002). Graphic ogranizers can be used within any discipline and have many applications in the teaching of science. Jamie McKenzie (1997), writing in the educational journal *From Now On,* says that "graphical [graphic] organizers convert complex and messy information collections into meaningful displays."

Some common graphic organizer forms are Venn diagrams, concept maps, flow charts, graphs, tables, matrices, and brainstorming maps. (**See Figures 3.12–3.16** beginning **on page 88** for examples of graphic organizers.) Once the basic idea of a graphic organizer is understood by a learner, the forms and applications are limited only by the learner's needs and imagination.

Researcher and educator David Hyerle (1996) prefers a broader and more inclusive name for the concept: "visual tools." Hyerle argues that "graphic organizer" is too limiting a label, because such tools can do much more than just organize information. They can support brainstorming, support the development of metacognition, and actually assist in the formation of knowledge.

Although we agree that "visual tools" is a more descriptive and pedagogically appropriate name for the idea of graphic organizers, we will use the latter term because it has become more common in the education field.

Why Use Graphic Organizers?

Viewing, using, and creating graphic organizers can enhance the learning of biology content as well as improve the thinking skills of students, especially those with learning disabilities (Begerid, Horton, and Lovitt 1990). Tracey Hall and Nicole Strangman (2004), of the Center for Applied Special Technology (CAST), conducted a literature review of graphic organizer research and found that ten of the twelve studies investigating the effects on learning of using graphic organizers showed some positive learning outcome. They also discovered that the most pronounced gains identified from using graphic organizers have been reported for postsecondary student populations.

Before the term "graphic organizer" was in vogue, the famous Russian psychologist L. S. Vygotsky (1962) said that "a visual graphic containing key ideas and information is easier to remember than extended text, whether the text is visual (writing) or verbal (speech)." One of the key benefits of using graphic organizers, therefore, is their memory-enhancing value; they help learners in setting up thinking/knowledge templates that can more effectively store and retrieve information. They can reveal the key structure and meaning of information more efficiently for students, which in turn reduces the volume of information that needs detailed processing (Ellis 1999).

A recent study conducted for Inspiration Corporation by Dr. Kimberly Hambrick and Dr. Kim Good of the Institute for the Advancement of Research in Education at AEL (Hambrick and Good 2003) revealed an additional benefit. Not only do graphic organizers aid in the retention and recall of information, they can help build students' critical thinking skills, especially when students create their own graphic organizers.

Using and making graphic organizers also supports the principles of schema theory: Based on prior experiences and knowledge, learners construct new knowledge in a multidirectional, nonlinear, and nonhierarchical way. A graphic organizer accommodates and encourages this kind of schema-based learning.

Effective Use of Graphic Organizers

Graphic organizers are particularly well suited for students with visual strengths, yet all learners can benefit from them. Careful and effective implementation of graphic organizers is key to maximizing student success. It is essential that any new graphic organizer form be adequately introduced and modeled, and that students be given multiple opportunities to practice using it in order to develop proficiency. Ongoing formative assessment through regular teacher-student interactions is also a critical component of using graphic organizers effectively (Hall and Strangman 2004).

The computer software Inspiration 7.5 (**see References** for company contact information) offers a whole suite of graphic organizer templates—some of which are specifically designed for scientific content—that make electronic construction easy. For some students, this software can be a valuable and motivating tool for making all kinds of graphic organizers.

It might be helpful to classify student use of graphic organizers into three categories: passive, active, and constructive. In *passive* use, students might view and interpret a graphic organizer from a textbook or one generated by the instructor. This could be as simple as assigning students to analyze a graph, a table, or a visual outline of a unit of study. Although this kind of use is sometimes appropriate and necessary, the overall learning value for students is likely to be minimal.

In *active* use, students might fill out a blank or partially completed graphic organizer presented in a textbook or made by the instructor. An example would be a Venn diagram comparing photosynthesis with cellular respiration where only some of the diagram is completed. Students would typically be assigned to add more information to the partially completed diagram.

Finally, with *constructive* use, students decide the type of organizer to use and/or the content it should contain. For example, students might be assigned to make a concept-map graphic organizer of a text chapter on Mendelian genetics.

Hyerle (1996) suggests that using graphic organizers only as simple fill-in-the-blank forms (active use) without encouraging student construction of graphic organizers has a limited pedagogical and intellectual value. For the best learning value, he believes the emphasis should be on constructive use. However, other researchers assert that a combination of student-generated (constructive) and teacher-generated (passive or active) graphic organizers seems to be the most effective strategy for students with learning disabilities (Crank and Bulgren 1993).

We believe that for best results, teaching students to use graphic organizers must be done incrementally and explicitly. An instructor designs and presents a graphic organizer and carefully models the process for using or constructing it. Eventually, for some graphic organizer applications, this approach can lead to successful student-constructed graphic organizers.

Developed Examples of Graphic Organizers within the *Biology Success!* Manual

In this manual are several examples of well-developed graphic organizers:

- A more detailed presentation, including several examples, on using concept maps to teach and learn introductory biology begins **on page 90**.
- There are two writing templates: a Lab Reporting Template (**page 163**) and a Writing Model for a Biological Process (**page 115**).
- We also include an experiment planning template (**Appendix C, "Student•Designing Controlled Experiments 9"**).

In addition, there are

- graphic organizers in the form of weekly course plans (**see page 36**),
- a course syllabus (**page 32**),
- assessment rubrics (beginning **on page 130**), and
- a textbook note-taking form (**see page 64**).

These are meant to provide just a sampling of ways to integrate graphic organizers into an introductory biology course. The possibilities are limitless and can all enhance the learning of biology content and skills for all students.

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Hutcheson, M. R. 2002. Teaching history and humanities. In *Teaching in the disciplines: Classroom instruction for students with learn-*

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Vygotsky, L. S. 1962. *Thought and language*. Cambridge, MA: MIT Press.

EXAMPLES OF GRAPHIC ORGANIZERS

Figure 3.12. Flow chart

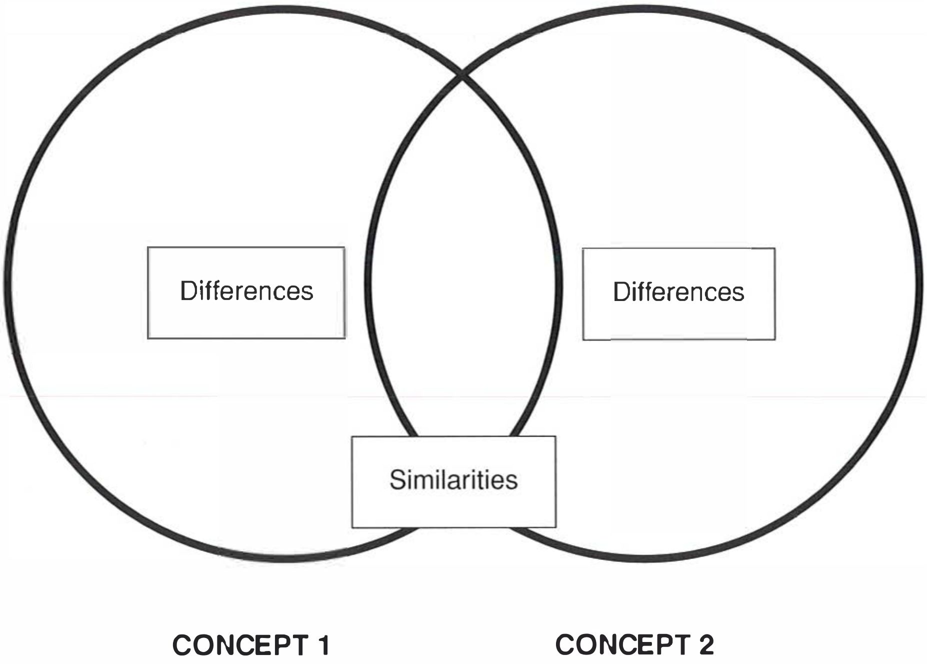


Figure 3.13. Venn diagram

	Item	Item	Item
Characteristic			
Characteristic			
Characteristic			

Figure 3.14. Matrix

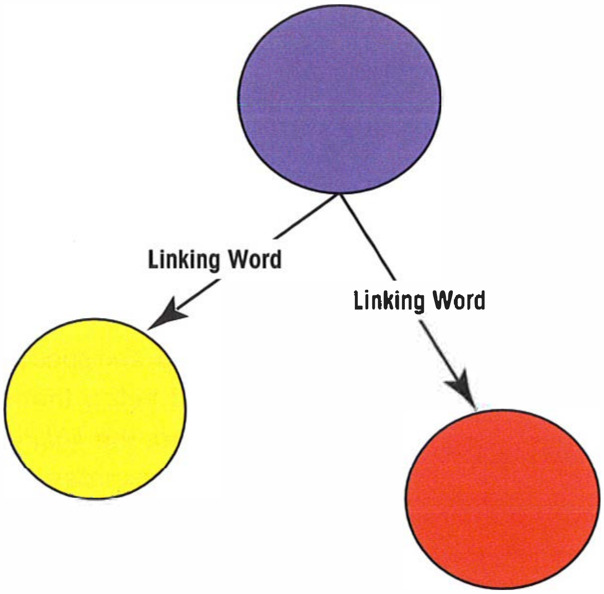


Figure 3.15. Concept map

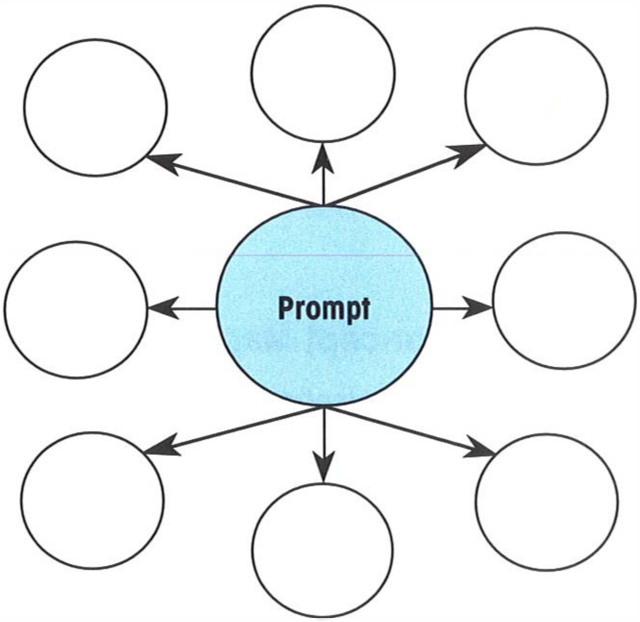


Figure 3.16. Brainstorm map

Using Varied Instructional Techniques: Concept Mapping

A CONCEPT MAP is a unique type of graphic organizer that can be used to enhance learning for all students in the biology classroom. A number of studies have shown positive outcomes associated with using concept maps for students with learning disabilities (Ruzic and O'Connell 2004). Biology content is particularly well suited for concept mapping. Concept maps can be constructed by students or teachers, but most research shows that student-generated maps have more educational value.

What Are Concept Maps?

Concept maps, developed by Joseph D. Novak and Bob Gowin (1984), are diagrammatic depictions of related terms and concepts that show the precise and explicit relationships between the concepts represented. They can be simple, as in **Figures 3.17 and 3.18**, or elaborate, as seen in Example A: Completed Concept Map **on page 96**.

The *concepts* are placed in boxes or "bubbles" in a hierarchical fashion; the most inclusive or overarching concepts are placed at the top, and specific concepts are placed or subsumed below them. Written along the lines or arrows are the *linking words*. These are key because they express the nature of the relationship between the concepts. The linking words should be concise and simple and the links should generally run vertically down the map. *Cross-linking* connections can be made horizontally across the map. These show relation-

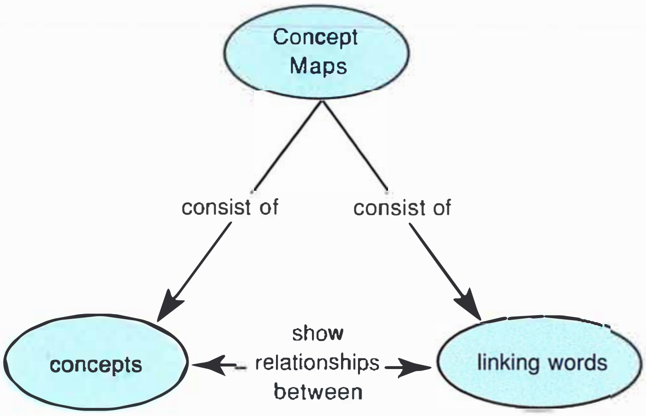


Figure 3.17. A brief concept map about concept maps

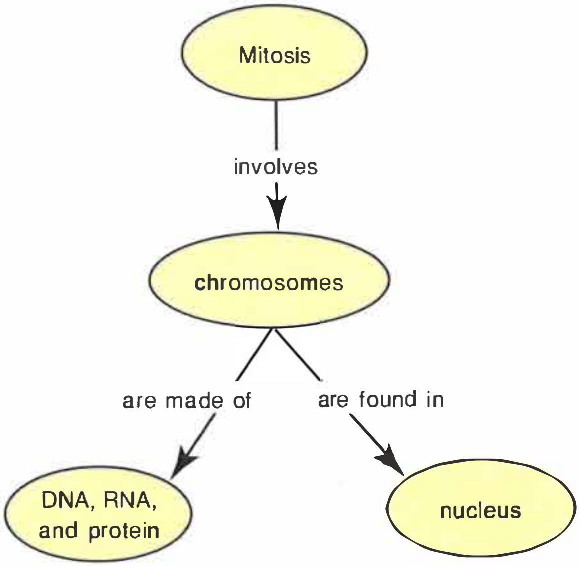


Figure 3.18. A brief concept map about mitosis

ships between different areas of a larger concept map. Effective cross linking shows a higher order of understanding of concept map relationships.

The Benefits of Concept Maps to Students

Concept maps can offer many benefits to students. They are particularly useful for visual learners because they represent content in a diagrammatic and spatial format. In addition, concept maps challenge learners to synthesize and build a unifying structure for course content; they create a big picture out of the details. They allow learners to actually construct knowledge. This task requires higher-order thinking, a goal in all educational settings for all kinds of learners. A well-constructed concept map also aids in creating a schema for memory; student retention of course content may improve.

The Uses and Benefits of Concept Maps to Teachers

For teachers, concept maps are versatile tools. They can be used in a number of places in an instructional sequence. Here are some examples:

- Student-generated maps can be used to assess prior knowledge and preconceptions of students. For example, at the beginning of a genetics unit, an instructor might ask students to generate five terms they associate with the study of genetics and then construct a small concept map that shows or explores the relationships among the terms.
- Concept maps can also be assigned as a note-taking tool during the process of reading a text chapter.
- They can be used as an in-class collaborative activity for teams of two to three students.
- They can be created by a teacher and used as an advance organizer to introduce a unit or presented as a summarizer at the end of a unit.
- Finally, a student-made map can provide an effective way for a teacher to assess student learning during or at the end of an instructional unit.

Suggestions for Using Concept Mapping in the Biology Classroom

Although concept maps are wonderful tools for learning, students often are skeptical of the idea initially. New strategies such as this take time to learn and can be frustrating. Students will not necessarily see the payoff until they have had some concept mapping experience. Therefore, it is important to carefully and consciously teach the process of concept mapping early in a course, so that students have sufficient time and multiple opportunities to practice the skill.

When introducing concept maps, start small and start with the familiar. Cover the basic idea and model the construction of a simple map, for instance using fruit, as in Figure 3.19. List the concepts to be included and collectively make the map on the chalkboard or with a projection device.

Fruit-related concepts: fruit (overarching concept), nutrition, apples, vitamin C, bananas, yellow, snack

Now let the students practice, alone or in teams, with another group of familiar concepts, such as those related to cars. Here is a sample list of car-related concepts:

Cars (overarching), roads, tires, engine, carburetor, speed limit, radiator, antifreeze, radials

After this activity, it is important for students to see the variety of maps that were made by the class. This demonstrates that there is no map that

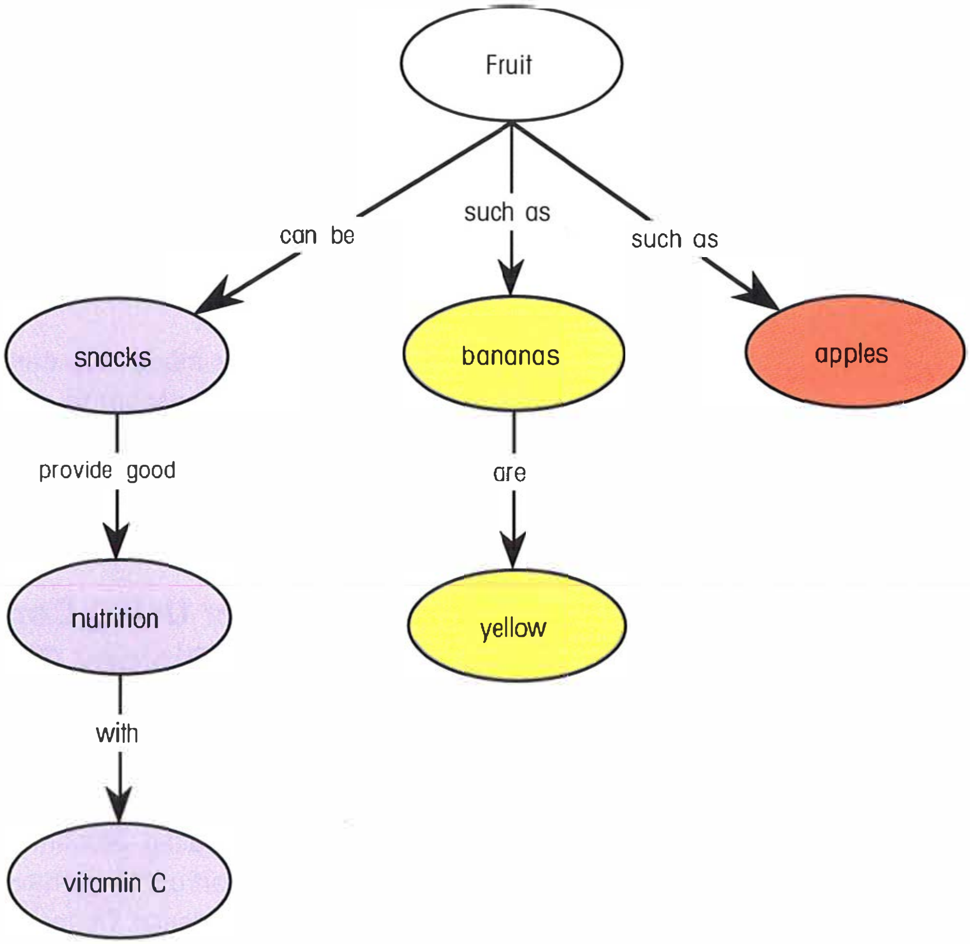


Figure 3.19. A practice concept map about fruit

is "right." Structure and linking language can vary and still represent the relationships well.

With the familiar under their belts, students will be ready to move on to biology-specific concept maps. If the goal is for students to ultimately create their own concept maps from course material, then it is important to continue building their confidence and facility with the technique. To achieve this goal, give students partially created maps that they must complete independently or collaboratively.

There are three kinds of partially completed concept maps: *concept*-focused, *link*-focused, and a *combination* of the two.

1. A partially completed *concept-focused map* has some concepts filled in while others are blank. All linking word language is included for the students. (**See Example B on page 97.**) An instructor can choose whether to include a concept "bank" (a list of concepts for students to select from) or to have the students find the appropriate concepts using their course resources.
2. A partially completed *link-focused map* has all the concepts included but lacks the linking word language. (**See Example C on page 98.**)
3. A *combination map* has some links and some concepts provided while others are not. (**See Example D on page 99.**)

Eventually, an instructor could give students just a list of concepts to map; the students provide the design and the linking language themselves. Ultimately, with students who are capable and concept map savvy, an instructor could leave the entire process up to them by giving assignments to map a textbook chapter or a unit of study. Using this incremental approach to building concept map proficiency will enhance student attitudes and confidence toward this teaching and learning strategy.

Construction Tools and Ideas

The computer software Inspiration 7.5 offers a concept map template option that makes electronic construction easy. All examples included here were made using this software. (**See References on page 94** for company contact information.)

Paper-and-pencil versions can work well too, allowing for easy revisions. Concept maps are works in progress. Clearly, multiple drafts are common, and to some extent necessary, as students solidify the depth of their conceptual understanding. But working on paper, erasing and overwriting, can sometimes result in a messy product. One way to avoid the messiness of the drafting process is to suggest that students write their concepts on sticky notes. This provides a flexible, tactile way to create a map that allows for trial and error without mess.

Using poster paper increases the size available for the map and may thus make the process easier for some students. If a map like the one in **Example D on page 99** is assigned in an 8½ x 11 inch format, the size, scope, and detail can be intimidating to some students. In addition to handing out the entire partially completed map, give students enlarged sections (as shown in **Example E on pages 100**), so that working with the map will be less overwhelming. When they are done completing the sections, students can then transfer the work to the entire map so they have a comprehensive copy as well.

The use of different colors or the inclusion of clip art and other visuals can also enhance the usefulness of the map for some visual learners. The idea is that these maps can become quite personalized.

Provide a list of common linking words or a linking word "bank." This may help students who struggle with generating specific language that describes kinds of relationships. A list of common or typical linking words is found **on page 95**. Hand this out to students separately so they may file it away for future applications.

Assessment

Robert K. Noyd, in his article "A Primer on Concept Mapping" (2000), offers some simple assessment guidelines for student-generated maps. The following questions could easily be transferred to a rubric format (**see page 127** for a discussion of using rubrics as an assessment tool):

Overall Map Organization (40 percent of assessment)

- Is the map organized from most general to more specific?
- Are all terms/concepts included and placed in appropriate locations within the map?

Linking Words (40 percent of assessment)

- Are the linking words precise and accurate in identifying the relationships between the concepts?

Cross Linking (20 percent of assessment)

- How many cross links are included? Do they accurately integrate the map?

References

Inspiration Software, Inc. 7412 SW Beaverton Hillsdale Hwy., Portland, OR 97225. 1-800-877-4292. http://www.inspiration.com.

Novak, J. D., and B. Gowin. 1984. *Learning how to learn*. New York: Cambridge University Press.

Noyd, R. K. 2000. A primer on concept maps. *Journal of Cooperation and Collaboration in College Teaching* 10 (1): 9–11.

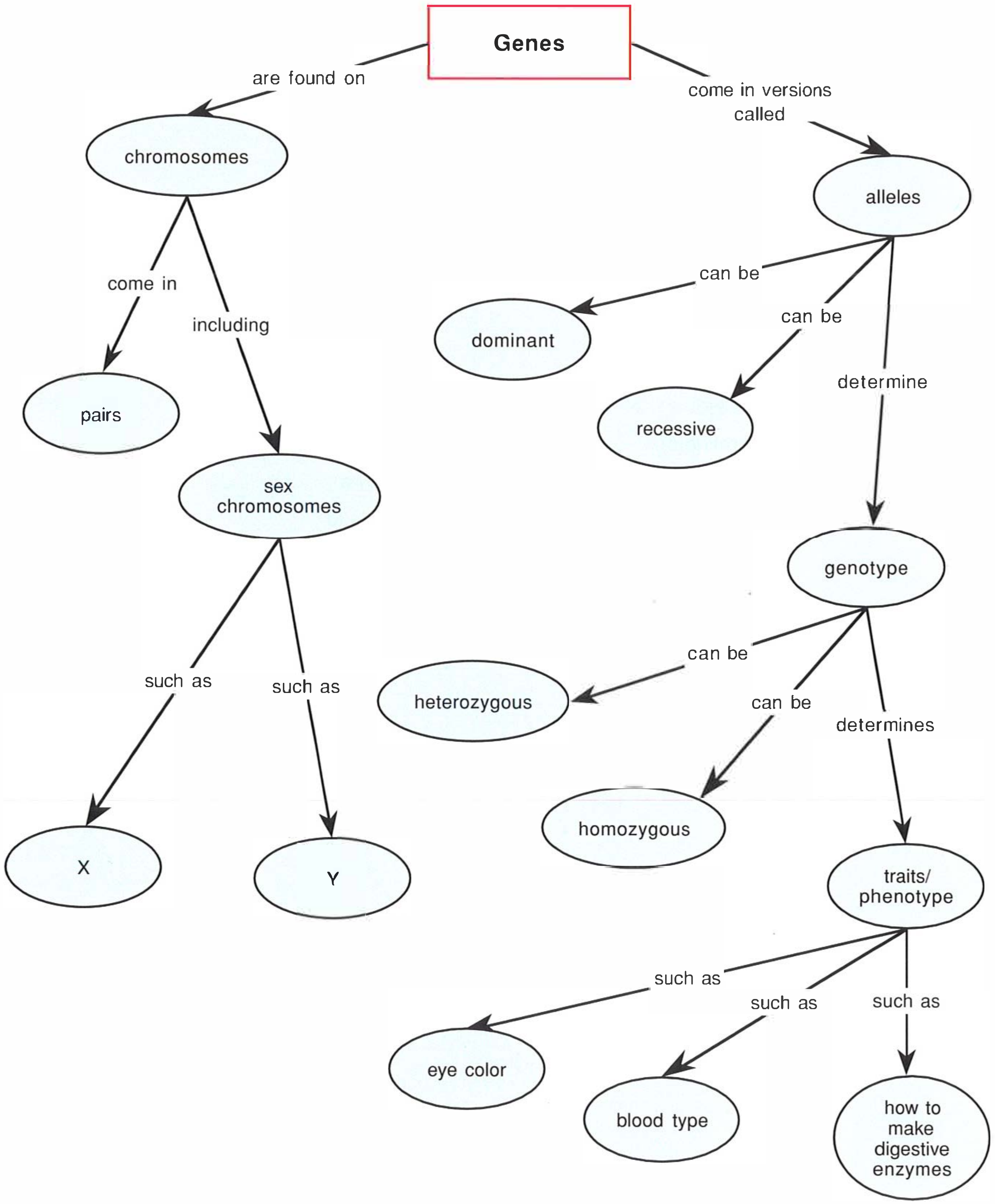
Ruzic, R., and K. O'Connell. 2004. *Concept maps.* Center for Applied Special Technology (CAST). http://www.cast.org/ncac/index.cfm?i=1669.

CONCEPT MAPS:

Commonly Used Linking Words and Phrases

composed of
includes
depends on
is influenced by
causes
is affected by
contains
is made by
can be
such as
determine(s)
is an example of
provides
functions as
lives in
occurs in
may indicate
have
are
is involved in
limits
uses
produces
consists of
influence(s)
shows
helps to

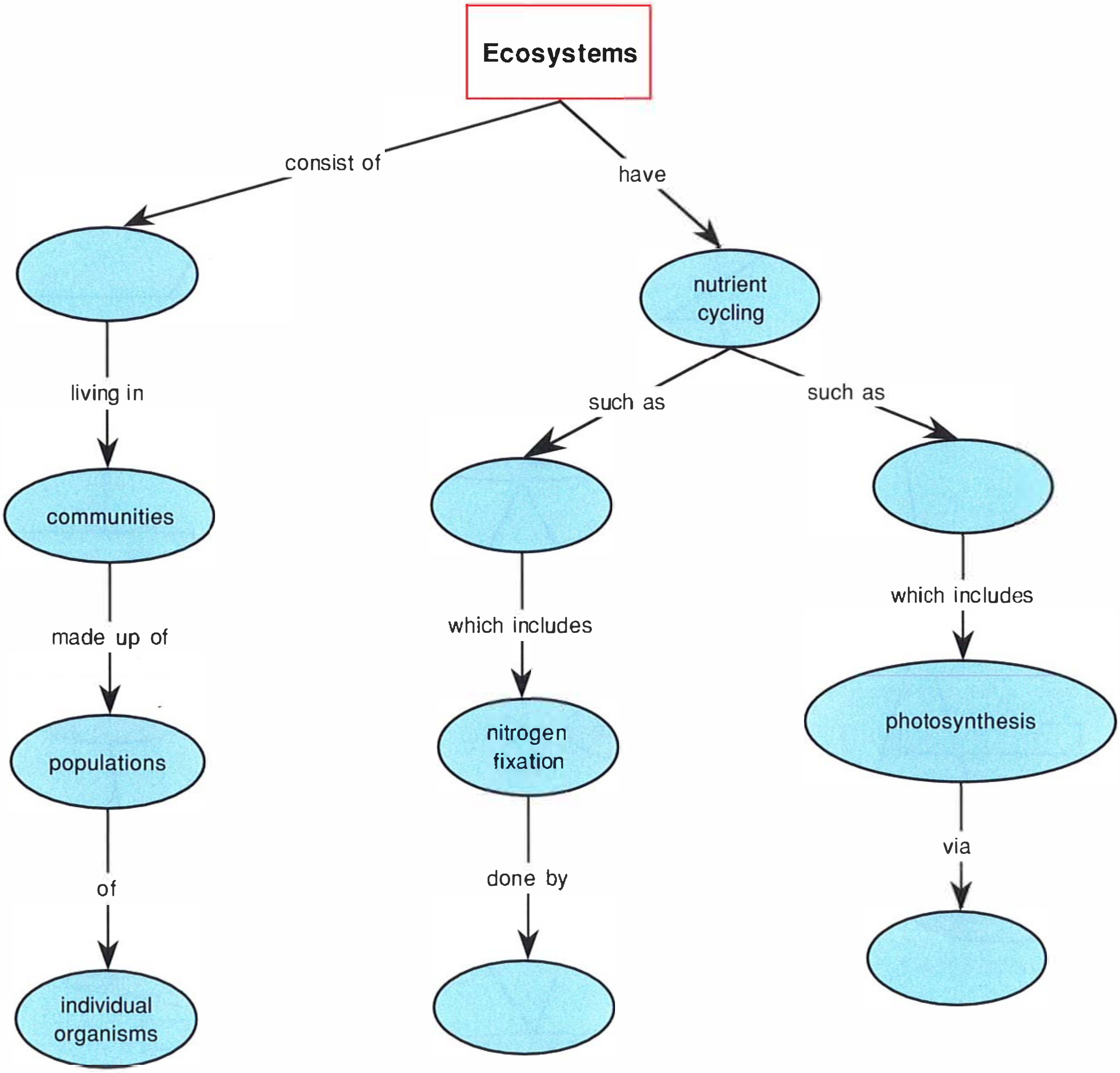
EXAMPLE A: COMPLETED CONCEPT MAP



EXAMPLE B: CONCEPT-FOCUSED CONCEPT MAP

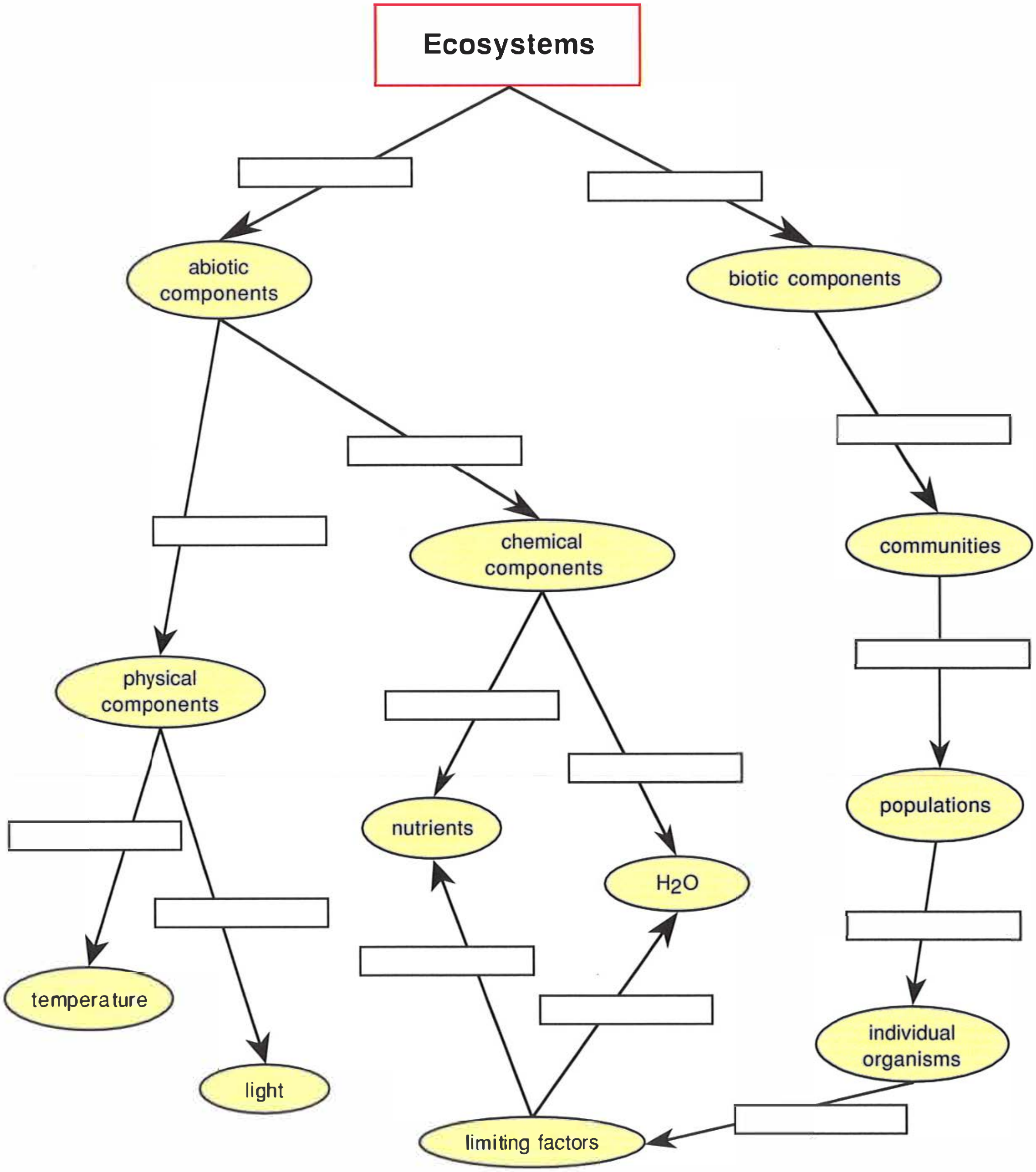
Instructions: Fill in the empty bubbles with the correct concept from the list below:

carbon cycle	**bacteria**
biotic components	**sunlight**
nutrients	**nitrogen cycle**
temperature	**carbon dioxide**



EXAMPLE C: LINKED-FOCUSED CONCEPT MAP

Instructions: For each link, fill in concise language that expresses the relationship between the "bubbled" concepts.



EXAMPLE D: COMBINATION CONCEPT MAP

Concept-Focused and Link-Focused

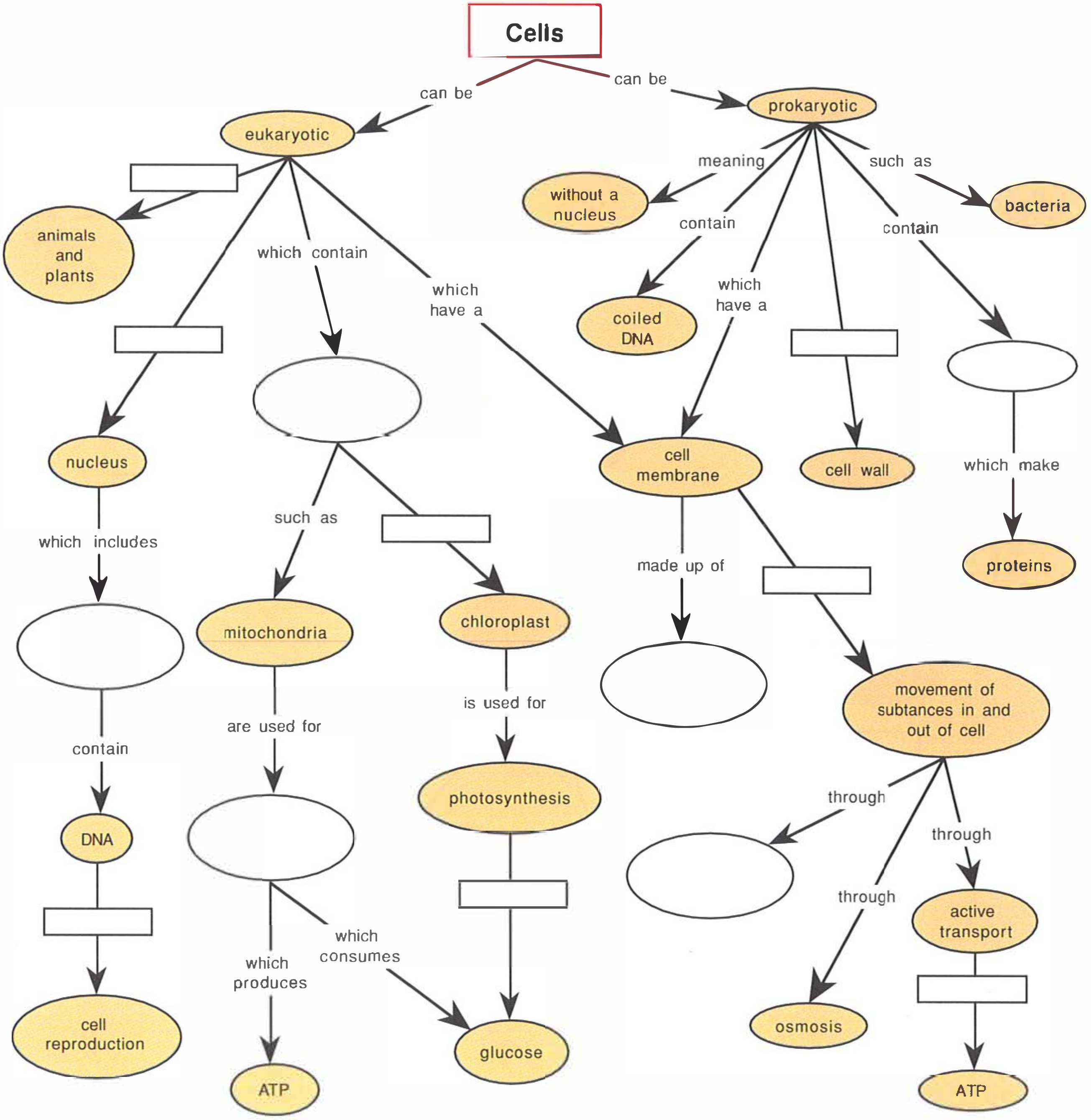
Instructions: Part A:

For each link that is not labeled, provide a concise word or phrase that expresses the relationship between the "bubbled" concepts.

Instructions: Part B:

For each bubble or box that is empty, choose one of the following concepts to fill it in with:

chromosomes, proteins and lipids, diffusion, ribosomes, organelles, cell respiration



EXAMPLE E: COMBINATION CONCEPT MAP

Enlarged Sections, page 1 of 2

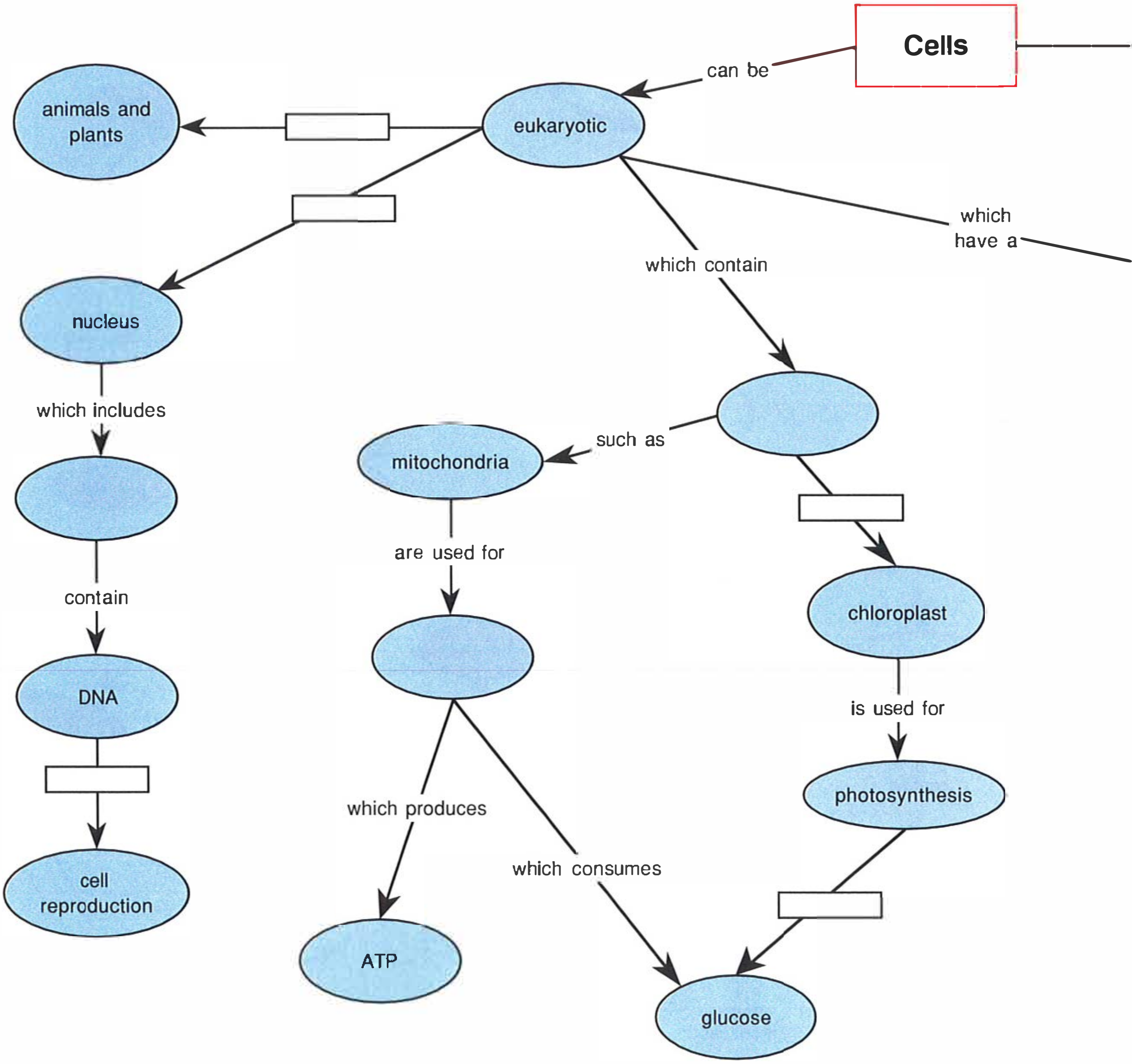
Instructions: Part A:

For each link that is not labeled, provide a concise word or phrase that expresses the relationship between the "bubbled" concepts.

Instructions: Part B:

For each bubble or box that is empty, choose one of the following concepts to fill it in with:

chromosomes, proteins and lipids, diffusion, ribosomes,organelles, cell respiration



EXAMPLE E: COMBINATION CONCEPT MAP

Enlarged Sections, page 2 of 2

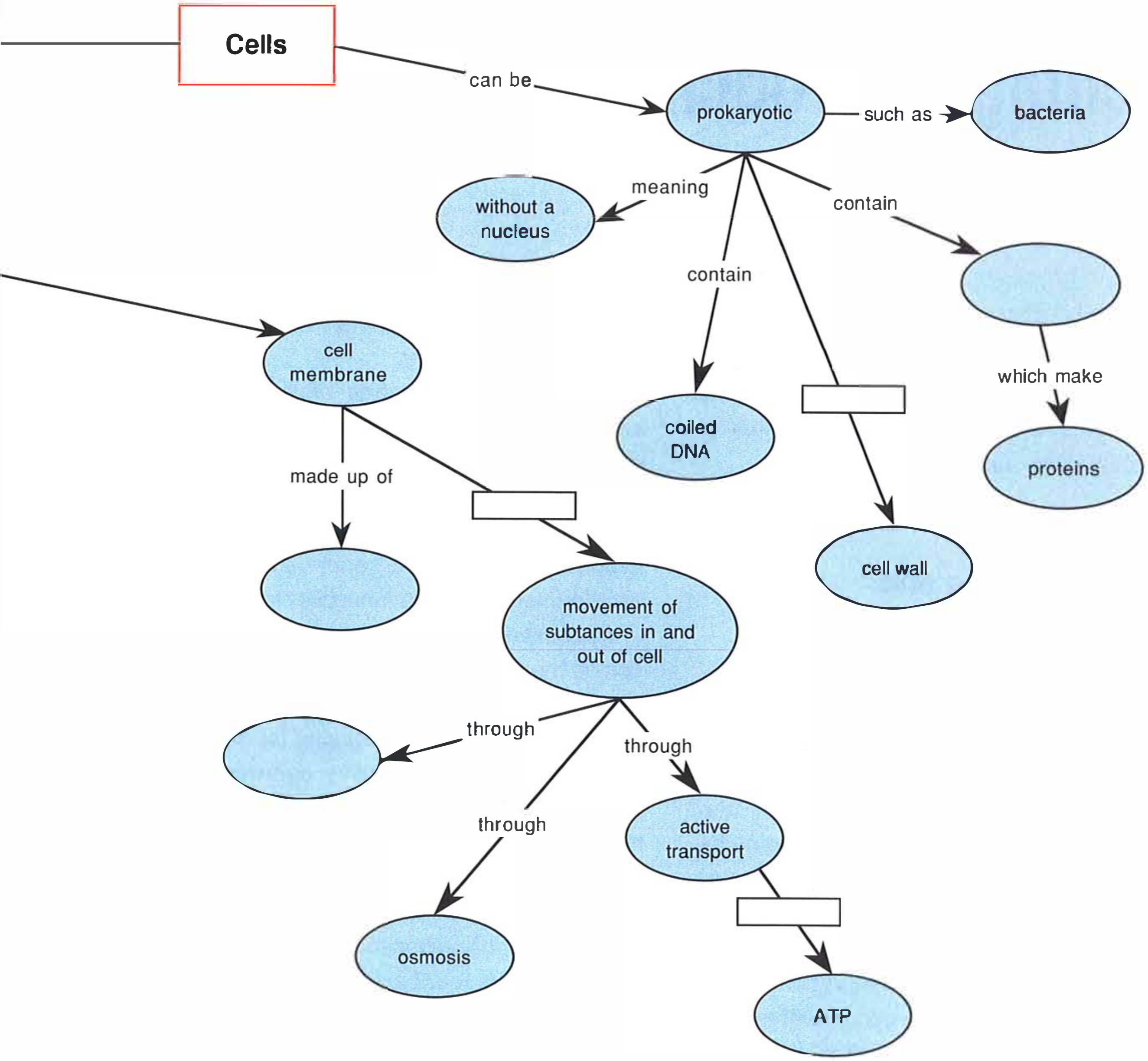
Instructions: Part A:

For each link that is not labeled, provide a concise word or phrase that expresses the relationship between the "bubbled" concepts.

Instructions: Part B:

For each bubble or box that is empty, choose one of the following concepts to fill it in with:

chromosomes, proteins and lipids, diffusion, ribosomes,organelles, cell respiration



Using Varied Instructional Techniques: Inductive and Deductive Teaching Approaches

IN ORDER to meet the needs of diverse learners in a biology classroom, it is important to vary the approach to teaching the content. One basic dichotomy related to approaches is that of inductive-deductive teaching.

What Are Inductive and Deductive Teaching?

Inductive teaching (also called *discovery teaching* or *inquiry teaching*) is based on the claim that knowledge is built primarily from a learner's experiences and interactions with phenomena. An instructor using an inductive approach begins by exposing students to a concrete instance, or instances, of a concept. Then learners are encouraged to observe patterns, raise questions, or make generalizations from their observations. The teacher's role is to create the opportunities and the context in which students can successfully make the appropriate generalizations, and to guide students as necessary.

Inductive teaching has close ties with the instructional method called the "learning cycle," where phenomena are explored before concepts are named. Inquiry-based teaching, in which students are asked to continually develop and test hypotheses in order to generalize a principle, is another member of the inductive "family."

Deductive teaching (also called *direct instruction*) is much less "constructivist" and is based on the idea that a highly structured presentation of content creates optimal learning for students. The instructor using a deductive approach typically presents a general concept by first defining it and then providing examples or illustrations that demonstrate the idea. Examples that do not fit the idea are helpful in confirming the idea. Students are given opportunities to practice, with instructor guidance and feedback, applying and finding examples of the concept at hand, until they achieve concept mastery.

Most "demonstration" or "cookbook" labs are deductive in nature. Students have already been introduced to the idea in their text or in lecture, and the lab serves to show them directly and concretely something that they already know or have been taught conceptually. They know the outcome of the procedure before it is completed. The three osmosis labs starting **on page 286** present a deductive version (demonstration), a transitional deductive/inductive version (structured inquiry), and an inductive version (guided inquiry), all based on the same materials.

Examples of Inductive and Deductive Ecology Lessons

The following two examples are meant to illustrate the two approaches.

Deductive

During an ecology unit, the instructor presents the concept of resource partitioning. It is defined: Resource partitioning is the dividing up of a key resource (habitat, food) in order to reduce direct competition between species. Examples of the phenomenon (such as a visual depiction of the famous warbler/spruce tree spatial partitioning example) are then shared with students and explained. Then the instructor asks students to apply their understanding by evaluating a new example (such as a wading birds/feeding depths visual depiction) and deciding whether it fits the concept of resource partitioning. The example is discussed, and students are given feedback on their choices and justifications. The teacher decides if additional examples are necessary in order for students to achieve concept mastery.

Inductive

During an ecology unit, the instructor provides students with a few visual depictions of ecological scenarios where resource partitioning is shown (the warblers/spruce trees and the wading birds/feeding depths examples, for instance). Students are instructed to observe and describe the examples and to look for any patterns they share. The instructor may ask a guiding question, such as What are some ways that competition can be minimized? Students then share their observations and interpretations of the phenomena, hopefully describing the unnamed concept of resource partitioning. After the discussion, the instructor provides the name of the concept for the students.

The Advantages and Disadvantages of These Approaches

Neither of these approaches is perfect for all students all of the time; each has advantages, disadvantages, and trade-offs.

Richard Felder (1993) characterizes inductive and deductive preferences as a learning style issue. Some students learn best through an inductive approach; some learn best through a deductive approach. Inductive learners *like* making observations and poring over data looking for patterns so they can infer larger principles. Deductive learners *like* to have the general principles identified and prefer to deduce the consequences and examples from them. These are often the same learners who prefer more structure in general.

From the example about resource partitioning described previously, one can see that the inductive approach could potentially make for a "messier" lesson. Students may draw other meanings from the examples and data provided than what was intended by the instructor. The inductive approach may also take more time and be less "efficient" than a deductive approach. In addition, certain ideas do not lend themselves easily to an inductive technique—teaching about DNA base pairs or photosynthesis, for instance.

Some educators have suggested that deductive teaching can be critically important for students with learning disabilities (Brigham and Matins 1999). This method has a clear and readily apparent structure, is easily paced to accommodate student needs, and is very familiar to students. But deductive teaching has trade-offs; it can be too rigid a form that does not allow for divergent student thinking nor emphasize student reasoning and problem solving.

Mary Bay et al. (1990) found that in a controlled study of science achievement by students with mild handicaps, including learning disabilities, those students taught by an inductive approach showed better long-term retention of concepts than those taught with a deductive approach. The hypothesis is that inductive thinking demands deeper processing.

At the same time, open-ended inductive exercises may pose severe challenges for students with learning disabilities. Such students may have difficulty getting started, understanding their role in the exercise, and staying focused on the activity. In order for these students to succeed when engaged in inductive activities, it is essential that the instructor create clear guidelines for behavior, provide explicit directions from the outset of the activity, and be prepared to offer extra guidance as necessary. Mastropieri, Scruggs, and Butcher (1997) concur and suggest that inductive-based activities for students with learning disabilities, without the supporting structures described here, will result in less effective concept development.

These pros and cons, however, should not steer an instructor away from using one approach or the other; both are important teaching models.

Ways to Integrate Inductive Teaching

Since inductive teaching is a less familiar approach to many biology teachers, two additional examples of inductive teaching are offered below.

1. Give students a basic data set in the form of a table or graph that shows a key concept, such as exponential growth. Ask them to observe the data, describe the data, and make some interpretations about the data. After the observations and interpretations have been discussed, introduce the name for the concept (exponential growth) and give them any other additional information deemed appropriate.
2. Play what is called the "inductive game." Provide a prompt in the form of a question or challenge, such as "List as many basic foods that humans consume as you can." Provide one or two examples so students catch on quickly (e.g., eggs, carrots). As the group names foods, record the responses for all to see in a simple table with three columns, leaving the heading for each column blank. The students will see that each response is placed in one of three different columns. (**See Figure 3.20**.)

   After several examples have filled all three columns, ask students to propose a classification system for the three-column table; in other words, what concept is the basis for the groupings? Collect and record the suggestions as the class discusses the merits of the various classification schemes proposed. Then write the appropriate name or definition for the groupings in the empty headings of the columns.

   In this case, the concept intended to be drawn out of the students was macromolecules: fats, proteins, and carbohydrates. Students will not typically identify the proper name of the con-

Mystery Heading (proteins)	Mystery Heading (fats)	Mystery Heading (carbohydrates)
Eggs	Olive oil	Potatoes
Turkey	Butter	Rice
Yogurt		Carrots

Figure 3.20. "Inductive game" example

cept, but that is not the point. The point is to look for patterns and propose a generalization that is supported by the examples.

Examples of Inductive Teaching Labs and Activities in the *Biology Success!* Manual

The *Biology Success!* manual contains two activities that are designed to be primarily **inductive**: "Mussel Beach: A Simulation of Evolutionary Change," beginning **on page 240**, and "Mendelian Genetics" beginning **on page 299**.

In Mussel Beach, students carry out a data-collecting simulation using beads and pencils, and they are asked to compare the results and draw conclusions before the key concepts are introduced.

In the activity Mendelian Genetics, students are given a structured and concrete experience of Mendelian principles using Legos before the corresponding genetics terms are introduced.

Examples of Deductive Teaching Labs and Activities in the *Biology Success!* Manual

The *Biology Success!* manual contains two activities that are designed to be primarily **deductive**: "Biogeochemical Cycles," beginning **on page 212**, and "Designing Controlled Experiments," beginning **on page 195**.

In Biogeochemical Cycles, students are led through a highly structured overview of biogeochemical cycles and then asked to practice writing about one example using a writing template.

In Designing Controlled Experiments, students work through a worksheet that defines and gives examples of key concepts of experimental design. They are then asked to practice using these concepts by designing an experiment of their own.

Conclusion

Both deductive and inductive teaching approaches should be included in a biology course. Each offers advantages to students with different learning strengths and motivations. Varying the approach to teaching content can help reach a broader number of students with diverse learning needs.

References

Bay, M., J. R. Staver, T. Bryan, and J. B. Hale. 1990. Science instruction for the mildly handicapped: Direct instruction versus discovery teaching. *Journal of Research in Science Teaching* 29 (6): 555–70.

Brigham, F., and J. J. Matins. 1999. A synthesis of empirically supported best practices for science students with learning disabilities. 1999 Annual International Conference of the Association for the Education of Teachers in Science, Austin, TX.

Felder, R. 1993. Reaching the second tier: Learning and teaching styles in college science education. *Journal of College Science Teaching* 23 (5): 286–90.

Mastropieri, M. A., T. E. Scruggs, and K. Butcher. 1997. How effective is inquiry learning for students with mild disabilities? *Journal of Special Education* 29 (2): 199–211.

Using Varied Instructional Techniques: Discussion

AT FIRST GLANCE, a biology teacher who knows something about learning disabilities might assume that classroom discussions offer an academic environment in which students with learning disabilities will flourish. After all, discussions don't entail burdensome reading and writing demands, and they do offer the interactivity often lacking in lecture formats. In many cases, this assumption will turn out to be true. But discussions also present their own obstacles for many students with learning disabilities because of students' difficulties in receiving or expressing information orally. This section spells out some of the challenges students with learning disabilities encounter in discussion-based classroom environments, as well as some ideas for structuring and managing a class discussion so all students can participate effectively.

Challenges to Effective Participation in Class Discussions

Some of the key characteristics students with learning disabilities may exhibit in a discussion-based environment are slow oral processing speed, difficulties with oral comprehension, attention issues, difficulties with expressing ideas, discussion anxiety, impulsive and/or dominating styles of participation, and difficulties with discussion decorum and pragmatics.

Students who cannot process oral language quickly or accurately find the meandering quality of discussions a special challenge—far more so than lectures, in which information is generally better organized and may be accompanied by visual referents. While a lecturer may pause to take or encourage questions and to ask students to summarize and reflect, class discussions may bounce from topic to topic in a seemingly random or contradictory fashion and never settle into a neatly condensed core of main ideas and secondary supports. The free-flowing nature of discussions also challenges students who are distractible, who tune in and out of the discussion while missing large chunks of information, or those who have difficulty with saliency, the ability to distinguish key points from less relevant context.

Class discussions also pressure students to be actively engaged in posing or answering questions and responding to statements. Many students with learning disabilities form part of the "silent majority" of the classroom—those who don't volunteer information for a variety of diagnostic reasons, "not the least of which is fear" (Herbert 2001). Students with learning disabilities often trade horror stories about having been humiliated or ridiculed by teachers or other students in earlier school settings for their "stupid" or inappropriate responses.

Another impediment to active participation for some students with language-based disabilities is verbal dysfluency: they struggle to formulate ideas into syntactically correct, clearly expressed sentences, or they experience word-retrieval difficulty and are unable to summon the terms for ideas they carry in their heads. Under the pressure of being called on to answer a question, they may fall silent or stammer an inarticulate response, making it seem as if they are uninformed or unmotivated. At the opposite end of this scale are students who dominate discussions or who interrupt others, sometimes to offer comments that seem off the topic. Frequently, problems with inattention or impulsivity are at the root of these behaviors.

Another group of students has problems understanding or participating appropriately in the nonverbal aspects of communication. Sometimes these students carry a diagnosis of nonverbal learning disability, but often they simply will be viewed as rude or clueless by their teachers and peers. These students may not have internalized some conversational basics, such as maintaining eye contact or taking turns. They may fail to grasp or convey tone of voice and body language, and thus miss irony, sarcasm, and many forms of humor, completely misunderstanding the intention of a remark or gesture.

Enhancing Student Participation in Class Discussions

Despite the problems that class discussions may pose, they are a vital component of most biology courses. With an understanding of the difficulties some students face, teachers can plan discussions so that all students benefit from the practice of the critical thinking and communication skills they embed.

Creating Class Rules

One of the best ways to address the hesitancy of some students to participate actively is to develop a set of classroom rules on the opening days of class. This goes along well with assessment of learning style (**see page 37–41**), because it supports the notion that class members must respect a diversity of learning styles and that all students must feel safe to express their ideas. Rules also provide explicit instruction in classroom expectations for the students who struggle with nonverbal communication. Students and instructors should cooperatively create rules for communicating with each other (Meehl 2002).

Some of the guidelines that have been consistently generated in communications classes at Landmark College include the following (E. Wood, personal communication, in Meehl 2002, p. 138):

- Respect each other
- Be open to others' thoughts and ideas
- Come prepared for class
- Offer constructive criticism
- Have fun

"These agreements between class members create a foundation that is conducive to meaningful learning" (Meehl 2002, 138) and are posted on classroom walls as a reminder of the "social contract" everyone has agreed on.

Providing "Wait Time"

Teachers and students are often uncomfortable with silent pauses in the classroom discussion and rush to fill in the silences. However, allowing fifteen seconds or so after posing a question to the class before you choose a respondent allows for slower processors to gather their thoughts and formulate more thoughtful responses. During this wait time, it can be beneficial to ask students to jot down some words or ideas that may help them articulate a clear and coherent response to the question. Also consider waiting a few seconds when responding to students, so that you model thoughtfulness to them.

Seating That Promotes Discussion

Arranging class seating so that students face each other is another simple way to promote good discussion. "When students sit in rows, they see many people's backs instead of their faces, which may in itself suggest negative implications for their meaningful working relationships." Organizing chairs into a circle or horseshoe promotes good eye contact and conversational flow. When the teacher sits among the students, instead of standing at the front of the room, "the locus of control shifts and a more egalitarian climate emerges" (Meehl 2002, 135). Chairs and tables can also be rearranged to facilitate working in pairs or small groups, giving students even more opportunities to learn by talking. Unfortunately, many biology classes are held in labs with seating determined by lab stations bolted to the floor. In these cases, discussion can be enhanced by moving the stools to a central area of the room or, if that isn't feasible, having the teacher sit among the students.

Setting Purpose

The first requirement of a successful discussion is to have a clear purpose. Is the central purpose to assess students' command of text material?—to probe students' abilities to apply previously learned information to a problem in the field?—to prepare students for a video they will be watching? All are legitimate goals, but all will require different types of questions. One of the built-in tensions of discussion-based teaching is that having a purpose is sometimes confused with arriving at a predetermined conclusion. This pitfall should be avoided, because students may feel manipulated rather than included if their questions and answers are bent to serve an instructor's hidden agenda.

Asking the Right Questions

The purpose of the discussion combined with the profile of the students should determine how the discussion begins. Often this is where the discussion goes awry. Instructors "preface" the discussion with a twenty-minute introduction, or ask a question that is too global for their narrow purpose or too restrictive for their expansive purpose. Two of the quickest ways to kill a discussion are for the instructor either to force students to complete his or her sentences, or to ask an open-ended question that assumes not only full command of all necessary information but also the ability to draw conclusions and make inferences based on it.

For example, a biology instructor may want students to think comparatively about Lamarckian and Darwinian evolutionary theories and at the end of the discussion be able to consider the characteristics of a good scientific theory. If the teacher feels the class has a firm grasp of the principles delineated by Lamarck and Darwin, the questioning could begin by asking the students to compare the two theories. On the other hand, if the teacher has reason to believe that most of the students still need to solidify their literal understanding, it would be better to begin by asking students to summarize the key points of each theory, and then create a visual on the board (such as a Venn diagram or a double-bubble chart) that lets students examine points of comparison. When the teacher feels the students are secure in understanding the ways in which Darwin's theory differs from Lamarck's, the next question would ask students "Which theory better accounts for the data?" Then the discussion can proceed to the more general issue by asking "What are the characteristics of a good scientific theory?"

Just as important as having an opening question suited to the purpose of the discussion is assuring that questions serve to keep students focused on the main purpose of the discussion. Following the comparison question in the previous paragraph with "Why do religious fundamentalists oppose teaching evolutionary theory in public schools?" will lurch the discussion in a very different direction than that established by the opening questions, and it may be hard to draw students back to the central issue of the scientific basis for evolutionary theory.

Assuring Equitable Participation

To be truly inclusive, discussion-based teaching must also find a means for involving the uninvolved. One approach that gets everyone involved in an equitable fashion uses the cooperative learning technique called *random group check*. To accomplish this, each class member is assigned a number, which is written on a slip of paper and deposited in a receptacle of some sort. To initiate answer-sharing and discussion, the instructor randomly chooses a number, and the student with the corresponding number is then accountable to respond to the first question. Informal, student-driven discussion can follow this initial structure, as other students may have different interpretations. For each new question discussed, however, employ the random group check to begin the discussion. The rationale for this technique is that it embeds in the activity the expectation of personal accountability for the work completed. Students know that they may be asked (in a random, non-personalized way) to participate, and they therefore take the activity more seriously.

Another specialized technique for helping reluctant or unfocused students overcome their hesitancy to participate is for teachers to let these students know in advance when they will be called on. A teacher generally knows what he or she is going to cover and can discreetly let students know they will be asked about a certain topic. This strategy has a number of excellent benefits: It brings reluctant students and their insights into the discussion, improving their confidence and facilitating acceptance by the larger group. It also gives students the necessary time to prepare their answers, while providing a point of focus to improve comprehension of other points of information.

A simple tactic, especially when distractibility seems to be the issue, is to begin a question with the student's name. This allows distracted students to focus on the question and avoid the feeling that they have been caught not paying attention. Teachers should also require students to speak in complete thoughts. If they offer one- or two-word answers, draw out more explanation with an encouraging phrase such as "tell me more."

Teachers can help reluctant or domineering participants improve their class participation by talking privately outside of class (after class or during office hours) to help them set goals for participation. A silent student might be encouraged to increase his or her participation to a minimum of two or three comments per class, while an overenthusiastic participant can be asked to reduce the number of comments, especially if there's a tendency to interrupt other students. Teachers can help students monitor their progress by encouraging them to keep a daily tally of how many times they participate or interrupt, and by providing an agreed-upon, discreet cue (such as scratching their left ear, or taking off their eyeglasses) for the targeted behavior.

Keeping Students Focused

There are several techniques for keeping students focused and productive during a discussion. First and foremost is for the instructor (and the students) to have a clear idea of the purpose of the discussion. Writing out the purpose or the overarching discussion questions on paper or chalkboard for all participants to see as a visual reference can help make this clear. It is also recommended that the length of discussions be limited: the longer the discussion, the more possibility there is of losing the attention of students. Gauge student "discussion span" early in a course and honor it.

Students often raise off-topic comments and questions during a class discussion, and these can be both annoying and amusing. The instructor's role as a facilitator is to contain and forward the discussion. This at times means verbally redirecting students back toward the topic. It is constructive to honor interesting but off-topic questions by recording them and raising them later at a more appropriate time.

Small-Group Work

Another way to promote equitable and focused discussion is by using small groups. Small-group discussions and tasks can provide an opportunity for students to rehearse the presentation of their ideas in a smaller, less anxiety-producing setting. **See** the "Science and Religion" activity **on page 237** for a detailed example. Assigning students specific roles can work well to promote equitable participation, and it is tremendously helpful in ensuring that all students have ample opportunities to practice their oral expression and critical thinking skills.

Common roles within small groups include

- facilitator: makes sure everyone participates and stays on topic;
- time keeper: moves the discussion along;
- recorder: takes notes; and
- reporter: presents the group's work to the rest of the class,

as well as some creative roles, such as illustrator or "devil's advocate." Teachers who use this form of small-group organization will need to spend time instructing students in the roles and supervising their practice. If they arrange the groups so that students play different roles from class to class, everyone will have a broad range of learning experiences by the end of the course.

Discussing Controversy

Discussing controversial topics can be an exciting part of an introductory biology course. The many relevant and interesting controversial topics can act as strong student motivators and promote discussion skills, biological literacy, and critical thinking. The same challenges and principles of effective participation in discussions described earlier pertain to controversies as well—perhaps even more so. One additional principle should be emphasized when facilitating discussions on controversial topics: maintaining instructor neutrality. This may be particularly important for students with learning disabilities, who, because of their already weak participation skills and background knowledge deficits, can be disproportionately influenced by an instructor's viewpoint. A biased instructor can interfere with the development of essential reasoning and argumentative skills in these students. The National Institutes of Health Curriculum Supplement Series on Infectious Diseases (1999) provides additional tips on leading students though controversial discussions in science.

Conclusion

Discussions may be more participatory than lectures, but they still involve processing a lot of talk, and they can be difficult for some students with attention or language-processing difficulties to follow. Therefore, discussions should be broken into smaller units, with opportunities for other multimodal activities: individual or group brainstorming, constructing a diagram, watching a video clip, or writing summary notes. Used this way, discussions can be not just an occasional respite from lectures, but also a means of teaching the critical thinking skills necessary to study biology.

References

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Sections of this chapter have been adapted, with permission, from the following Landmark College publications:

Herbert, C., and S. W. Strothman. 2001. Considerations in classroom management. In *Promoting academic success for students with learning disabilities*, ed. S. W. Strothman, 51–81. Putney, VT: Landmark College.

Hutcheson, M. R. 2002. Teaching history and humanities. In *Teaching in the disciplines: Classroom instruction for students with learning disabilities*, ed. L. C. Shea and S. W. Strothman, 167–85. Putney, VT: Landmark College.

Meehl, J. J. 2002. Oral expression in the college classroom: Creating communication climates for collaborative learning. In *Teaching in the disciplines: Classroom instruction for students with learning disabilities*, ed. L. C. Shea and S. W. Strothman, 121–50. Putney, VT: Landmark College.

Using Varied Instructional Techniques: Writing Models

STUDENTS BENEFIT from having explicit guidelines for assignments, particularly those involving writing. Providing models or graphic templates is a useful method for improving students' writing. Such templates can be used for laboratory reports (**see page 163**), article summaries, critiques, and "process" writing—writing that explains or describes a particular biological process, such as photosynthesis, cellular respiration, mitosis, meiosis, protein synthesis, or biogeochemical cycles.

The "Writing Model for a Biological Process" template found **on page 115** could be of great value to students whose teachers ask them to know the details of these biological processes. An example of a filled-out template using the biological process of cell division is also provided **on page 117**.

Suggestions for Using the "Writing Model for a Biological Process"

In order to get students proficient with writing about biological processes using the model, or template, an instructor could facilitate the following activities to provide explicit instruction and practice:

Activity 1

Before assigning to students the task of writing about a biological process, introduce the writing model by having students write about a familiar everyday process using the template as their guide. Examples might be making breakfast or getting to class or pumping gas at a gas station. This could be done collectively with the entire class. The instructor could display the template for all to see and record student responses in the blank boxes. When the model is complete, discuss how it could be used to describe a biological process.

Activity 2

1. Before class, take a recently introduced biological process, such as cellular respiration, and write a sample explanation using the Writing Model for a Biological Process as a guide.
2. Write the specific and discrete parts of the explanation (purpose, essential features,

Step A, etc.) on strips of colored paper. Do not label or identify the components on the strips—just include the text.

3. Mix up the strips and place them in envelopes, making as many envelopes and strips as needed for the class or group size.
4. Distribute one set of strips in an envelope per group of students.
5. Give them the task of sequencing the strips according to the Writing Model for a Biological Process and their understanding of the process.
6. Compare and discuss the results with students when they complete their work. Be sure to include some metacognitive components in the discussion: What aspects of this task were challenging? How did you approach the task?

Activity 3

Use a procedure similar to that in Activity 1, but this time write about a biological process that has recently been discussed.

Activity 4

After students have gained some familiarity with the model and its use through the suggestions described above, give them the following task:

1. Assign students to use the Writing Model for a Biological Process to write their own summary of a different process, such as photosynthesis, that has already been discussed in class.
2. When students are finished drafting their individual summaries, pair them up in class for a peer review and feedback session. Suggest that student pairs use the template's guidelines as a checklist for assessing the completeness of each other's work.
3. Discuss with the entire class their experience with this assignment, paying attention not only to the content but to their metacognitive reflections on using the model, and to the benefits and challenges of peer review.

WRITING MODEL FOR A BIOLOGICAL PROCESS

Follow these steps when describing a biological process

Name of Process: ______________________________

1. State the purpose and/or importance of the process (1–2 sentences) →	Purpose/Importance
2. Summarize the process by answering this question: What are its essential features? (1–2 sentences) →	Essential Features
3. Start at the beginning of the process (if a cycle, start at a logical starting point) A. Elaborate on Step A. For example, provide details on: • Components • Relationships between components • Specific outcomes or products of the step →	Step A
B. Elaborate on Step B. For example, provide details on: • Components • Relationships between components • Specific outcomes or products of the step →	Step B

C. Elaborate on Step C.
For example, provide details on:
- Components
- Relationships between components
- Specific outcomes or products of the step

Step C

Continue until the last step of the process is described. If it's a cycle, continue until you have arrived back at your starting point.

4. State a conclusion about the process you have described, either paraphrasing **Step 1** or **Step 2** or adding a new insight (1–2 sentences)

Conclusion

WRITING MODEL FOR A BIOLOGICAL PROCESS

Follow these steps when describing a biological process

Name of Process: Cell Division/Mitosis

1. State the purpose and/or importance of the process (1–2 sentences)	**Purpose/Importance:** The purpose of cell division/mitosis is to carefully create additional cells from existing cells in order to promote an organism's growth and maintenance.
2. Summarize the process by answering this question: What are its essential features? (1–2 sentences)	**Essential Features:** The essential features of cell division involve the replication and distribution of chromosomes in one cell in order to create two new, or daughter, cells. This occurs in various phases.
3. Start at the beginning of the process (if a cycle, start at a logical starting point) **A.** Elaborate on Step A. For example, provide details on: • Components • Relationships between components • Specific outcomes or products of the step	**Step A:** In interphase, the chromosomes are replicated in preparation for division.
B. Elaborate on Step B. For example, provide details on: • Components • Relationships between components • Specific outcomes or products of the step	**Step B:** In prophase, the chromosomes become dense and visible, the nuclear envelope disappears, the centrioles move toward the poles of the cell, and the spindle fibers begin to form.

C. Elaborate on Step C.
For example, provide details on:
- Components
- Relationships between components
- Specific outcomes or products of the step

Step C: In metaphase, the spindle fibers align the chromosomes along the so-called metaphase plate, halfway between the centrioles at the poles of the cell.

D. Elaborate on Step D.
For example, provide details on:
- Components
- Relationships between components
- Specific outcomes or products of the step

Step D: In anaphase, the sister chromatids begin to move apart and toward the centrioles at the opposite poles of the cell.

E. Elaborate on Step E.
For example, provide details on:
- Components
- Relationships between components
- Specific outcomes or products of the step

Step E: In telophase, the chromatids arrive at each pole, the nuclear envelope reappears, and the spindle fibers dissolve.

F. Elaborate on Step F.
For example, provide details on:
- Components
- Relationships between components
- Specific outcomes or products of the step

Step F: Cytokinesis then occurs to complete the division of nonnuclear parts of the cell.

4. State a conclusion about the process you have described, either paraphrasing **Step 1** or **Step 2** or adding a new insight (1–2 sentences)

Conclusion: Through these steps, cell division/mitosis ensures that hereditary information contained in a cell is carefully replicated and disseminated into new cells.

Using Varied Instructional Techniques: Effective Review

ALL LEARNERS benefit from reviewing course material on a regular basis. Reviewing helps to consolidate or recode information in long-term memory for later retrieval. Furthermore, the ways in which we review new ideas and concepts can affect our long-term retention. For example, a student who reviews notes on cell respiration by silently reading the notes taken weeks ago tends to have less retention than a student who paraphrases the notes, then writes the paraphrases next to the original set of notes.

In addition, students who learn to review by applying their strengths to the reviewing process will retain and utilize that information more effectively. For example, a student who learns and remembers best by discussing ideas with another learner would do well to apply this technique in reviewing course information. Or a visual learner could make a flow chart or a mind map of the concepts. Students who are more aware of their learning style strengths and weaknesses can better develop and apply specific, effective reviewing strategies.

Listed and explained in this section are several strategies that teachers and students can use when reviewing course material. It is important for the instructor to explicitly introduce and model these strategies in class in order to help students fully understand how they could be used, and also suggest that students choose the most appropriate strategies for their learning style. Encouraging students to use these strategies develops their self-understanding while reinforcing biology content, and gives them practice with techniques that could be applied elsewhere in their academic work or profession.

Some of the review activities described may work best when done individually. Others might be more useful if performed in collaboration with other students. When appropriate, working with partners to brainstorm or generate ideas may be more effective than working alone. A combination approach in which students develop ideas independently but then share them with another student afterwards is another possibility.

Samples of Review Strategies

Use of Study Guide

During review sessions early in a course, the instructor should supply students with a set of review questions or a study guide. A sample study guide is found **on page 148**. As the course proceeds, ask students to take on more responsibility to develop their own review questions from course material. Encourage students to employ a strategy that best fits their learning style when responding to the study guide questions. Some examples follow:

- **Visual Responses to the Questions.** Encourage visually strong learners to choose a graphic or pictorial method of expressing their answers. For instance, they could use colors, pictures, arrows, or words to enhance a drawing, or they might use a Venn diagram or some other form of graphic organizer.
- **Use of a Computer.** Some students may best express their answers using a computer. The method could be as simple as word processing instead of hand writing answers, or more complex, such as constructing a graphic organizer using the Inspiration software program, or a table or spreadsheet using Microsoft Excel software or a Web page.
- **Model Building and Manipulatives.** For learners who like to work with their hands and can link concepts in three dimensions, suggest that they build a model for some review questions. The instructor would need to make available some basic materials—for example, some of those listed in the sidebar **on page 83**.

Student Lessons

As teaching is great way to test knowledge and demonstrate understanding, give students the option of preparing a brief lesson for the rest of the class on one of the concepts to be reviewed.

Review Games

Following is a list of games that can be used effectively for review:

- **Bingo.** The teacher provides students with a blank template for a bingo board and lists twenty-four terms or concepts to be reviewed. (Alternatively, the teacher may ask the class to generate the list.) These twenty-four terms get entered randomly on the bingo boards. (Don't forget the FREE space!) The teacher then reads out the definitions, provides examples, or uses visual cues for the terms. For example, the teacher might show a diagram of a completed Punnet square and ask the question "What type of inheritance is being demonstrated?" The students might then guess the answer to be "sex-linked inheritance" and cover that square. This continues until someone gets BINGO. After a few runs, students might want to volunteer to lead the activity.
- **Round Robin or Round Table.** Have students form groups of three to five, and provide a question that would generally require a list of answers, such as "Name eight parts of the cell and their functions." In a *round robin*, students talk among their group (as robins chirp), and one student records the answers. If the *round table* option is chosen, students circulate a paper and generate the list silently in writing (tables don't talk). Students who can't add something may pass the paper along. Groups signal when they have completed the task. This particular strategy is excellent for a class wrap-up, or as a way to begin a class by reviewing information from a previous class.
- **Cue Cards.** If students have been keeping index cards with terms on one side and a pic-

ture on the other, they can place their cards on the table. As the teacher provides a definition or example of a term, students hold up the appropriate card in front of them. (Individual white boards work well too.) This is a quick way for teachers to check on the progress of individuals and of the group.

- **Pictionary or Charades.** Give the group a prompt—for example, "Describe a function of one of the four major macromolecules." Students present their ideas as pictures or charades. The class could call out their guesses or list them on a piece of paper to check with answers later. Alternatively, the teacher could assign each student a specific concept or term, such as divergent evolution, to draw or act out.

- **Biojeopardy.** The teacher generates major categories within the unit that is being reviewed and designs questions within each category (or assigns these tasks to the students as homework or class work.) Groups are formed and then take turns choosing questions that they answer as a group. (Assigning a group spokesperson is usually a good idea.) At the end, a "final jeopardy" question is given to all groups, and the winners are declared.

Conclusion

Spending class time teaching students how to review may seem like a task that takes time away from introducing and covering more content. However, the authors of this manual believe that the time invested in teaching effective review will result in better and more motivated student learning. Encouraging students to find and practice effective methods that express their understanding of course material affirms the idea that we are diverse learners with many ways to approach solving a problem or answering a question. Appropriate review strategies engage students with the content more fully and creatively, and help to further develop their understanding of how they learn best.

Assessing Student Performance: An Overview of Assessment

MUCH HAS been written about the assessment of student learning in science. The National Science Education Standards, meant to guide the nation in reforming the teaching and learning of science, contain an entire chapter describing the design and use of effective assessment (National Research Council 1996). The purpose of this overview is not to repeat what others have done so well, but to provide a summary of the key principles of assessment, especially as they relate to students with learning disabilities.

Assessment is much more than just assigning a grade to a specific assignment or to a student's overall performance in a course. It encompases a range of activities that help instructors improve the effectiveness of their teaching and that assist students in becoming better and more active learners. Good assessment practices help make student thinking and conceptual development clearly visible, both to themselves and to others (National Research Council 2001).

Our understanding of the importance of thoughtful assessment is growing. According to the National Research Council, emerging research on learning indicates that careful and regular feedback from instructors who are experts in the content and mode of inquiry for their discipline is critical in developing among students a more advanced understanding of key concepts and skills in any subject (National Research Council 2003).

To be most effective, assessment starts with a clear understanding of the learning objectives or desired student outcomes for any course activity. Articulation of learning objectives is based on educational values, the skills that students should develop, the content they should know, and why they should know it (Astin et al. 1996). From there, the most appropriate assessment devices for measuring student achievement can be determined.

The Three Basic Types of Assessment

It is important to distinguish the three basic types of assessment: diagnostic, formative, and summative.

Diagnostic assessment is the process of determining what students already know (content knowledge) and what they can do (skills) as they begin a course or unit. All students, especially those with learning disabilities, can show a broad range of biology/science background knowledge as well as skill strengths and weaknesses. As described in "Six Guiding Educational Principles" and "Student Background Knowledge" earlier in this manual, using techniques for collecting diagnostic information is helpful for instructors as they plan their instruction to meet their learning objectives. Gathering diagnostic information through various and ongoing assessment techniques is also essential for establishing an effective teacher/student relationship. A simple example of diagnostic assessment in biology would be to give students the task of making a mind map that shows their understanding of natural selection before beginning instruction on this key biological concept.

Formative assessments are the informal and ongoing ways in which we gather and share feedback with students as they progress toward meeting the stated course objectives. Formative assessment is critical in establishing a learning and teaching "feedback loop": that is, determining what students are *learning* and adjusting *teaching* strategies accordingly. It is important to note that formative assessment is meant to support learning and should not result in the assignment of grades.

Most instructors use some type of formative assessment every day in their courses. The most common is interactive classroom discussion—hearing students formulate their understanding of the skills and content that guide the course. Other common methods of formative assessment are practice quizzes, observing small-group problem solving activities, and assigning multiple drafts of writing assignments in which students can continually revise their writing based on instructor feedback.

Summative assessment is the certification of learning or mastering the stated course objectives. Grades are assigned and credits are given based on this kind of assessment data. Often, summative assessment occurs at the end of a course unit, and several of these assessments may constitute the official determination of whether a student has met the course objectives. Large-scale examinations, final drafts of written reports, and oral presentations are the most common examples of this kind of assessment.

Key Principles of Assessment as Applied to Students with Learning Disabilities

Make Clear All Assessment Criteria

It is essential to provide students who have learning disabilities with an explicit accounting of the criteria that will be used to assess their work. These criteria should carefully match the course learning objectives. The sharing of criteria with students can take many forms, from a bulleted checklist to an elaborate scoring rubric (**see "Rubrics," page 127**).

Make Assessments Frequent

Students with learning disabilities benefit immensely from regular formative assessment practices. Establishing a routine of assessment and feedback helps students stay focused on their learning and gives them a realistic appraisal of their academic progress. Encourage them to meet with you outside of class during office hours, so that they take some responsibility for their role in the assessment feedback loop.

Allow for Ongoing Revision of Student Work

Make it common practice for students to gather formative feedback on their work and revise their learning products accordingly. In writing classes, students often develop multiple drafts of their essays, gathering instructor feedback along the way. Apply this same practice to lab reports or graphic organizers that are assigned.

Use Varied and Alternative Assessments

Both formative and summative assessments should be varied to allow for diverse learners to express their progress toward meeting course objectives. Using only one type of assessment, such as a written test, is not a reliable way to measure learning in all students (National Research Council 2001; Doran et al. 2002). Give students a chance to provide evidence of their learning through so-called "alternative assessments." For "formative assessments," include informal writing, discussion, graphic organizers, construction of simple models, and your observations of students working in class. For "summative assessments," use oral presentations, poster presentations, more involved models or graphic organizers (such as concept maps), formal writing assignments, experimental designs, and portfolios. (**See "Testing" on page 140** for more on alternative assessments.)

Self-Assessment

Incorporating some form of student self-assessment into the overall assessment process can help students in many ways. Most importantly, it helps students become reflective or metacognitive learners, adept at observing and analyzing their own work (National Research Council 2001). Self-assessment takes the learning objectives out of the hands of instructors and puts them in the hands of learners, so learners can appraise their own progress. A simple method of self-assessment would be for students to write and submit a list of their strengths and weaknesses related to each assignment. A more involved and useful technique would be to assign scoring rubrics as the self-assessment tool. Give students the specific learning objectives and grading criteria for their assignments and have them submit a self-scored rubric along with their work.

More on Assessment

We have included three additional essays on particular aspects of assessment. "Rubrics" (**page 127**) describes the value of using scoring rubrics to assess student work and provides several example rubrics. "Poster Presentations" (**page 151**) describes the value and how-to's of organizing a student poster presentation assignment. Finally, "Testing" (**page 140**) describes how to make traditional testing a better teaching and assessment tool.

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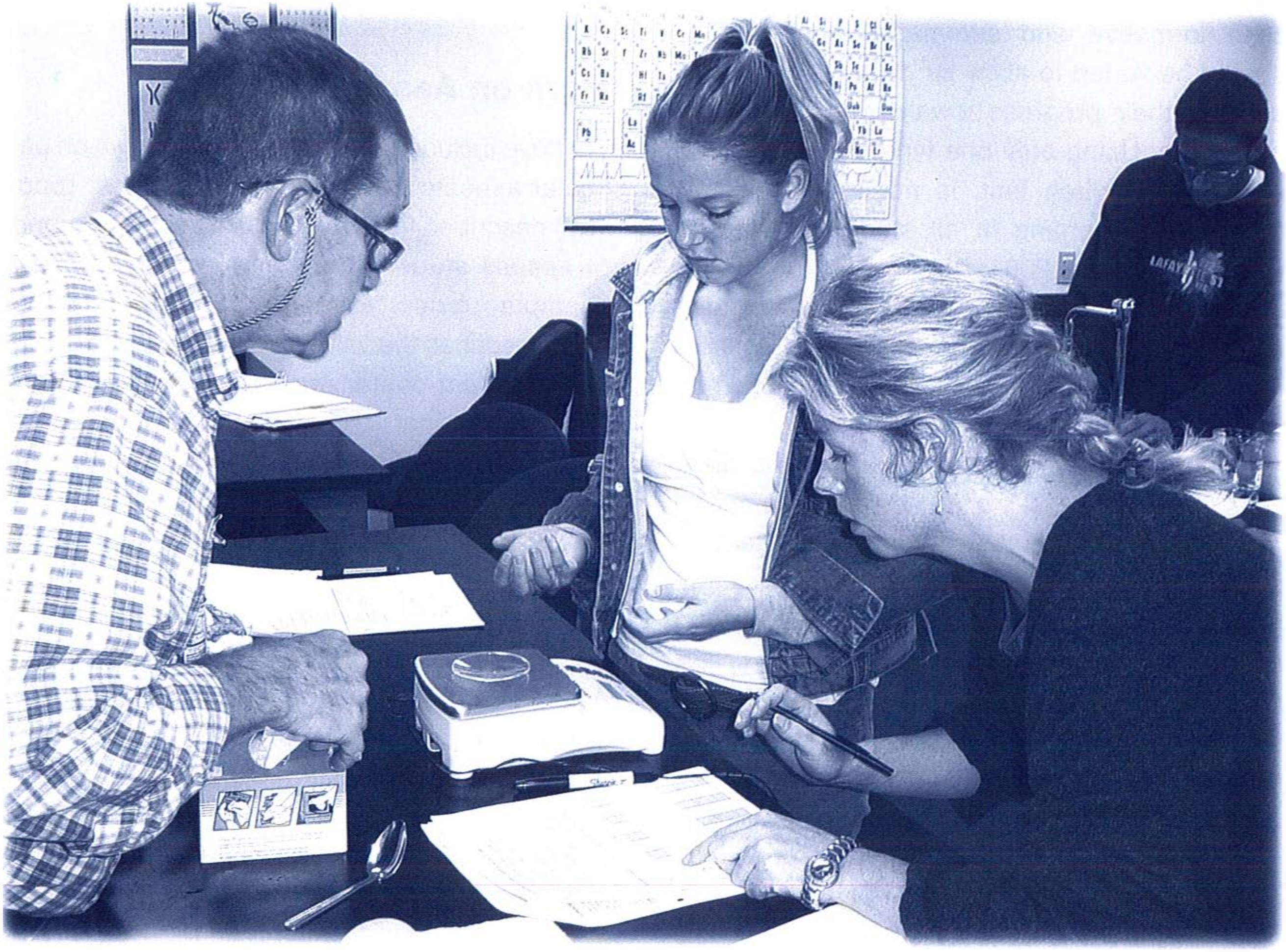

Assessing Student Performance: Rubrics

RUBRICS—or *scoring rubrics* or *matrices*, as they are sometimes called—are grid-formatted assessment devices. The row headings list specific areas of assessment. The columns describe the characteristics of student work in each assessment area needed to meet specific levels of quality. Rubrics also include specific point allocations for each area of assessment (**see Figure 3.21**). Rubrics can be an effective tool in the biology classroom for assessing performance-based tasks, including assignments such as laboratory reports, oral presentations, poster displays, portfolios, concept maps, or any form of writing.

Why Use Rubrics?

While rubrics may take some time to design and lay out, especially for the first-time designer, they have particular advantages that make them well worth the effort. Rubrics illustrate the value of basing instruction and assessment on clear objectives and of fostering self-understanding and self-efficacy in students (guiding educational principles 5 and 6).

Constructing a rubric requires that instructors be clear about the learning objectives they have for a particular assignment. Explicit descriptions of high-quality and low-quality work are developed by the teacher and shared with students via the rubric before an assignment begins. If used effectively, through emphasis and review, the rubric's descriptions of mastery can guide a student successfully through an assignment. Both teachers and students know what is expected and strive for it. And if students are given multiple opportunities during a course to work on a particular kind of assignment, such as laboratory reports, they will get to know the rubric well and be able to chart their progress in each specific area of assessment.

Over time, it becomes easier for students to monitor and reflect on their own progress toward meeting the learning objectives for assignments and courses. They will discover which aspects of assignments are most difficult for them to perform well, and in which aspects they excel. The rubric thereby encourages self-assessment and metacognition. Students begin to use the rubrics to plan how to complete assignments and can therefore assess their own work before they pass it along to their teacher. For students with learning disabilities who may need as many concrete tools as possible for guiding their work, rubrics can anchor them effectively as they work through a performance-based task.

How to Use Rubrics Effectively

To use rubrics effectively, it is important to keep several principles in mind. First, a rubric is effective only if the language used in it is unambiguous. This applies particularly to the characteristics of work required to meet the various levels of quality. Vague descriptions will neither guide student work nor make it easy for the instructor to assess that work. It is best to avoid overly general descriptors like "creative" or "complete" and instead focus on defining what is meant by *creative* (includes an original idea, integrates two related ideas, etc.) or *complete* (includes title, statement of purpose, graphs, etc.). If possible, use quantitative language in the descriptions (*exceptional*—includes five sources of information; *developing*—includes 2–3 sources of information, etc.). Similarly, it is best to avoid excessive detail so as not to overwhelm students with text-based information. Strike a balance between precision of descriptions and their conciseness. As a rule of thumb, rubrics should be no more than one to two pages in length.

For best results, introduce students to rubrics early in a course and spend some time uncovering their structure and purpose. It is quite possible that students may never have encountered rubrics in their previous courses. Also, it is advisable to use the same general rubric for assessing similar kinds of assignments. For example, when assessing lab reports, descriptions of the qualities that constitute an "exceptional" hypothesis should not vary from lab task to lab task. Those qualities remain the same no matter the application. Finally, it is also essential to distribute rubrics for performance-based assignments when an assignment is given, or very soon thereafter. Otherwise, they have little

Areas of Assessment	**Description of Levels of Quality**			**Comments/Points**
	Exceptional Work (full credit)	**Developing Work (partial credit)**	**Incomplete Work (no credit)**	
Area of Assessment #1 (10 points)	As specific as possible a description of what constitutes *exceptional* work in this area	As specific as possible a description of what constitutes *developing* work in this area	As specific as possible a description of what constitutes *incomplete* work in this area	A place for comments that justify instructor's assessment in this area
Area of Assessment #2 (5 points)				
Area of Assessment #3 (15 points)				

Figure 3.21. A generalized rubric

value to the students in planning and completing the assignment.

It may be helpful for students to get some practice using a rubric before they turn in their work. Consider distributing a mock student-written lab report and assigning students to assess it according to your lab reporting rubric. Have students compare their assessment results. This can be a valuable discussion, and can provide some diagnostic information about students as well.

For some students, a complete rubric may be overwhelming upon first encounter. To prevent this, pass out the rubric in pieces over some period of time and allow students to get familiar with its parts incrementally. Consider initially using a rubric to assess only one section of a lab report, such as the introduction. Eventually, add other sections until an entire lab report rubric is included in student assessment.

Scoring Rubrics

While rubrics can add much-needed clarity and objectivity to assessment practices, instructor subjectivity is still present. The biggest challenge is allocating points to "developing" areas of a rubric. For example, take an assessment area with a maximum possible allocation of ten points. Partial credit in this area could range from one to nine points. This leaves a lot of room for subjectivity. The use of the "Comments" column can be important in outlining the reasons for partial credit.

Examples of Rubrics

We have provided the following examples of specific rubrics for readers to investigate:

- A "Rubric for an Inquiry-Based Biology Laboratory Report" ("Comments/Points" column blank) that demonstrates how a rubric could be applied to standard lab writing assignments that are based on inquiry or experimental work. **See page 130.**
- A "Scored Rubric for an Inquiry-Based Biology Laboratory Report" ("Comments/Points" column filled in) that shows how an instructor might use the lab report rubric to score student work. **See page 132.**
- A "Master Notebook Assessment Rubric" that could be used by an instructor to monitor and assess student progress with organizing course materials and taking class notes. **See page 134.**
- A "Course-Wide Learning Objectives and Assessment Rubric." This example shows how a rubric can be used to summarize student performance for an entire course. **See page 135.**
- A "Poster Presentation Assessment Rubric" that could be used to evaluate student poster presentations. **See page 154.**
- A "Mussel Beach Simulation Assignment Packet" that includes an assignment overview, writing guidelines, and an assessment rubric specific to that assignment. The purpose is to show how a rubric can be integrated with other assignment documents. **See page 252.**

AN EXAMPLE OF A RUBRIC FOR AN INQUIRY-BASED BIOLOGY LABORATORY REPORT

Lab Section	Area of Assessment	Qualities of Excellent Work (full credit)	Qualities of Developing Work (partial credit)	Qualities of Incomplete Work (no credit)	Comments/Points
Introduction	Background Information (1 point)	Provides useful and relevant background information that sets the study in proper context	Provides some background that sets the study in context, but lacks some key information	Missing, or does not at all describe the necessary background for understanding the study	
Introduction	Purpose/ Experimental Question (1 point)	Purpose of study is explicitly stated; experimental question is included and explained	Purpose of study and experimental question are stated but not clearly; missing some part of explanation	Missing or inaccurate	
Introduction	Hypothesis and Predictions (1 point)	Hypothesis and predictions stated clearly in an "if–then" format	Hypothesis and predictions included but not in the "if–then" format	Hypothesis and prediction missing or irrelevant to study	
Introduction	Variables (1 point)	Identifies the independent, dependent, and controlled variables	Includes an identification of the independent, dependent, and controlled variables, but one may be missing or misidentified	Lacks identification of the independent, dependent, and controlled variables	
Methods	Methods and Materials (2 points)	Experimental procedure described in a clear sequence of steps that another investigator could reasonably follow	Experimental procedure described, but some important steps may be missing	Missing, or written in a way that is difficult to interpret	
Results	Data Presentation (1 point)	Tables or graphs are appropriately titled, labeled, and easy to read and interpret	Tables and graphs have some element (title, labels) missing, therefore making graph difficult to read and interpret	Missing, or tables/ graphs are missing all key features (title, labels, etc.), making interpretation impossible	

Lab Section	Area of Assessment	Qualities of Excellent Work (full credit)	Qualities of Developing Work (partial credit)	Qualities of Incomplete Work (no credit)	Comments/Points
Results	Written Description (1 point)	Clearly and completely describes the most important results shown in the data; avoids interpretation	Describes some but not all of the important results from the data; may include some interpretation not appropriate for this section	Missing, or does not at all describe most important results, perhaps focusing only on interpretation	
Discussion	Interpretation of Results (1 point)	Draws accurate and defendable conclusions from the data collected	Draws some accurate and defendable conclusions from data, but may be missing some critical interpretations of data	Missing, or the conclusions drawn are illogical or irrelevant	
Discussion	Confirm or Revise Hypothesis (1 point)	Relates findings of study back to original hypothesis and prediction and confirms or revises these initial ideas	Relates findings back to original hypothesis and predictions, but connections made are incomplete or confusing	Missing, or illogically connects findings to original hypothesis/ predictions	
Discussion	Further Study (0.5 point)	Lists specific and testable ideas for further study of topic	Lists ideas for further study, but some may be too general or untestable	Missing, or presents ideas for further study that have no direct relevance to current study	

OVERALL GRADE/COMMENTS:

AN EXAMPLE OF A SCORED RUBRIC FOR AN INQUIRY-BASED BIOLOGY LABORATORY REPORT

Lab Section	Area of Assessment	Qualities of Excellent Work (full credit)	Qualities of Developing Work (partial credit)	Qualities of Incomplete Work (no credit)	Comments/Points
Introduction	Background Information (1 point)	Provides useful and relevant background information that sets the study in proper context	*Provides some background that sets the study in context, but lacks some key information*	Missing, or does not at all describe the necessary background for understanding the study	*Background does not include:* *— citations* *— reference to key source* *0.75 points*
Introduction	Purpose/ Experimental Question (1 point)	*Purpose of study is explicitly stated; experimental question is included and explained*	Purpose of study and experimental question are stated but not clearly; missing some part of explanation	Is missing or inaccurate	*1 point*
Introduction	Hypothesis and Predictions (1 point)	*Hypothesis and predictions stated clearly in an "if-then" format*	Hypothesis and predictions included but not in the "if–then" format	Hypothesis and predictions missing or irrelevant to study	*1 point*
Introduction	Variables (1 point)	*Identifies the independent, dependent, and controlled variables*	Includes an identification of the independent, dependent, and controlled variables, but one may be missing or misidentified	Lacks identification of the independent, dependent, and controlled variables	*1 point*
Methods	Methods and Materials (2 points)	Experimental procedure described in a clear sequence of steps that another investigator could reasonably follow	*Experimental procedure described, but some important steps may be missing*	Missing, or written in a way that is difficult to interpret	*Missing explanation of how data was analyzed and with what instruments* *1.5 points*
Results	Data Presentation (1 point)	Tables or graphs are appropriately titled, labeled, and easy to read and interpret	*Tables and graphs have some element (title, labels) missing, therefore making graph difficult to read and interpret*	Missing, or tables/graphs are missing all key features (title, labels, etc.), making interpretation impossible	*One graph lacks title and axis labels* *0.75 points*

Lab Section	Area of Assessment	Qualities of Excellent Work (full credit)	Qualities of Developing Work (partial credit)	Qualities of Incomplete Work (no credit)	Comments/Points
Results	Written Description (1 point)	*Clearly and completely describes the most important results shown in the data; avoids interpretation*	Describes some but not all of the important results from the data; may include some interpretation not appropriate for this section	Missing, or does not at all describe most important results, perhaps focusing only on interpretation	*1 point*
Discussion	Interpretation of Results (1 point)	*Draws accurate and defendable conclusions from the data collected*	Draws some accurate and defendable conclusions from data, but may be missing some critical interpretations of data	Missing, or the conclusions drawn are illogical or irrelevant	*1 point*
Discussion	Confirm or Revise Hypothesis (1 point)	*Relates findings of study back to original hypothesis and prediction and confirms or revises these initial ideas*	Relates findings back to original hypothesis and predictions, but connections made are incomplete or confusing	Missing, or illogically connects findings to original hypothesis/ predictions	*1 point*
Discussion	Further Study (0.5 point)	Lists specific and testable ideas for further study of topic	*Lists ideas for further study, but some may be too general or untestable*	Missing, or presents ideas for further study that have no direct relevance to current study	*Only untestable ideas included 0.25 point*

OVERALL GRADE/COMMENTS: 9.25/10.5, or 88%

AN EXAMPLE OF A MASTER NOTEBOOK ASSESSMENT RUBRIC

Name: ____________________

Assessment Period: ____________________

Specific Area of Master Notebook	Characteristics of A-Quality Work (4 points)	Characteristics of B-Quality Work (3 points)	Characteristics of C-Quality Work (2 points)	Characteristics of D-Quality Work (1 point)	Characteristics of F-Quality Work (0 points)
Filing System	All course materials are filed in the appropriate section according to system suggested in syllabus (unless you have told me of an alternative system)	Most materials are filed in the appropriate section according to system suggested in syllabus. A few items are misfiled.	Only some of the materials are filed in the appropriate section according to system suggested in syllabus. Many items are misfiled or unfiled.	Master notebook functions only to hold the assemblage of course materials. No system of filing is practiced.	No master notebook is in use.
Chronology	All course materials are dated and in chronological order within their appropriate section	Most course materials are dated and in chronological order within their appropriate section. A few items are undated or out of chronological order.	Only some course materials are dated and in chronological order within their appropriate section. Many items are undated and out of chronological sequence.	No course materials are dated and in chronological order within the notebook.	No master notebook is in use.
Note Revision	There is ample evidence of note revision practices, such as questions posed in note margins; sweat pages are present; additional information not recorded in class has been added (from text or from memory), or highlighters/colors have been used to mark key terms or ideas. These practices are consistent across the notebook.	There is some evidence of note revision practices, such as questions posed in note margins; sweat pages are present; additional information not recorded in class has been added (from text or from memory), or highlighters/colors have been used to mark key terms or ideas. However, these practices are not consistent across the notebook.	There is minimal evidence of note revision practices, such as questions posed in note margins; sweat pages are present; additional information not recorded in class has been added (from text or from memory), or highlighters/colors have been used to mark key terms or ideas. These practices are infrequently used across the notebook.	There is no evidence of note revision practices in the notebook.	No master notebook is in use.

Master Notebook Grade for This Assignment Period: ________

Comments:

EXAMPLE OF A COURSE-WIDE LEARNING OBJECTIVES AND ASSESSMENT RUBRIC

Explanation of Rubric:

The rubric beginning on the next page is meant to show students how well they met the stated course objectives for an entire course. It lists the various course objectives in the left-most column and then attempts to carefully describe three possible levels of mastery for each of those objectives in the remaining columns. Each objective has been assigned a relative percentage weight of the course grade, summarized at the end of the rubric under "Grading," so that students can know the importance of any particular objective.

Also, each mastery level has been assigned a relative percentage range, so that specific grades can be assigned for each objective. For example, a student who scores 82 percent on course objective number 6 (the Packing-Peanut Lab) has demonstrated a moderate level of mastery for that objective. This way, objective mastery is explicitly linked with grades. It is also important to note that each written or performance-based objective (numbers 6 through 14) has a more detailed rubric that guides the assessment for that objective. This course-wide rubric essentially shows a summary of each of those more-elaborated rubrics.

This rubric should be distributed to students and previewed near the beginning of the course. It can then serve as a midterm progress report and/or a final progress report.

Course Learning Objectives	Level of Mastery— High (87–100%)	Level of Mastery— Moderate (74–86%)	Level of Mastery— Low (less than 74%)
1. Demonstrate understanding of key biological overview and scientific inquiry concepts through a variable format quiz (Quiz 1)	Student scored 87–100 %	Student scored 74–86 %	Student scored less than 74%
2. Demonstrate understanding of key evolutionary concepts through a variable format quiz (Quiz 2)	Student scored 87–100 %	Student scored 74–86 %	Student scored less than 74%
3. Demonstrate understanding of key genetics concepts through a variable format quiz (Quiz 3)	Student scored 87–100 %	Student scored 74–86 %	Student scored less than 74%
4. Demonstrate understanding of key ecological concepts through a variable format quiz (Quiz 4)	Student scored 87–100 %	Student scored 74–86 %	Student scored less than 74%
5. Demonstrate understanding of key cell biology concepts through a variable format quiz (Quiz 5)	Student scored 87–100 %	Student scored 74–86 %	Student scored less than 74%
6. Understand and apply the scientific method of inquiry through laboratory report writing **(Packing-Peanuts Assignment) See specific rubric for this assignment for more detail**	Student **fully** demonstrates the ability to use and apply scientific method through report writing. **Shows strong skill** in being able to: — articulate investigative questions — describe testable hypotheses and predictions — design and communicate clear procedures that test hypothesis — represent data graphically — summarize results — draw appropriate conclusions	Student **inconsistently** demonstrates the ability to use and apply scientific method through report writing. **Shows some gaps** in being able to: — articulate investigative questions — describe testable hypotheses and predictions — design and communicate clear procedures that test hypothesis — represent data graphically — summarize results — draw appropriate conclusions	Student **rarely** demonstrates the ability to use and apply scientific method through report writing. **Shows notable gaps** in being able to: — articulate investigative questions — describe testable hypotheses and predictions — design and communicate clear procedures that test hypothesis — represent data graphically — summarize results — draw appropriate conclusions

Course Learning Objectives	Level of Mastery—High (87–100%)	Level of Mastery—Moderate (74–86%)	Level of Mastery—Low (less than 74%)
7. Understand and apply the scientific method of inquiry through laboratory report writing **(Mussel Beach Simulation Assignment) See specific rubric for this assignment for more detail**	Student **fully** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)	Student **inconsistently** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)	Student **rarely** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)
8. Understand and apply the scientific method of inquiry through laboratory report writing **(Osmosis Assignment) See specific rubric for this assignment for more detail**	Student **fully** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)	Student **inconsistently** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)	Student **rarely** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)
9. Understand and apply the scientific method of inquiry through laboratory report writing **(Monogenics Traits Assignment) See specific rubric for this assignment for more detail**	Student **fully** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)	Student **inconsistently** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)	Student **rarely** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)
10. Understand and apply the scientific method of inquiry through laboratory report writing **(Pond Investigation Assignment) See specific rubric for this assignment for more detail**	Student **fully** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)	Student **inconsistently** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)	Student **rarely** demonstrates the ability to use and apply scientific method through report writing (See bulleted list in Objective 6)
11. Demonstrate key learning about project research through a written midterm progress report **See specific rubric for this assignment for more detail**	Student progress report **fully describes** learning objectives for project, **clearly summarizes** key biology learned, describes preliminary results, and suggests next steps for research	Student progress report **partially describes** learning objectives for project, or **may not clearly summarize** key biology learned; description of preliminary results **may be inaccurate**, suggestions for next research steps may be poorly conceived	Student progress report may be **missing some key components,** such as learning objectives, summarizing learning, description of preliminary results, and next research steps
12. Demonstrate key learning about project research through a poster presentation (DOUBLE WEIGHTED) **See specific rubric for this assignment for more detail**	Student poster shows an **in-depth application** of scientific method and/or presents project content **comprehensively** and displays elements of effective, visually appealing poster design	Student poster **shows some aspects** of an in-depth application of scientific method and elements of effective, visually appealing poster design	Student poster **shows minimal aspects** of an in-depth application of scientific method and elements of effective, visually appealing poster design

Course Learning Objectives	Level of Mastery—High (87–100%)	Level of Mastery—Moderate (74–86%)	Level of Mastery—Low (less than 74%)
13. Demonstrate the application of actively reading the course textbook. **See specific rubric for this assignment for more detail**	Assessments show that textbook is highlighted and margin-noted **thoroughly and appropriately.** Highlighting roughly follows the 20 percent rule: Only two lines out of ten lines are highlighted. If appropriate, different highlighting colors are employed. Margin notes include paraphrases, comments, questions, and various symbols (e.g., numbers, ?, *, etc.)	Assessments show that textbook highlighting is used, but is too minimal or too much. Margin notes are used, but **could be more extensive/complete** and could show better use of paraphrases, comments, questions, and various symbols	Assessments show that there is only **minimal evidence** of active reading in the textbook
14. Demonstrate the application of organizing and managing the course master notebook **See specific rubric for this assignment for more detail**	Assessments show that the filing system, chronological order, and note revision practices in the master notebook **meet instructor guidelines**	Assessments show that the filing system, chronological order, and note revision practices in the master notebook **partially meet instructor guidelines**	Assessments show that the filing system, chronological order, and note revision practices in the master notebook **do not meet instructor guidelines**
15. Demonstrate active in-class participation	Student **regularly** offers appropriate comments and questions about text readings and course topics, and attentively listens to classmates during small- and full-group discussions	Student **occasionally** offers appropriate comments and questions about text readings and course topics, and attentively listens to classmates during small- and full-group discussions	Student **seldom** offers appropriate comments and questions about text readings and course topics, and attentively listens to classmates during small- and full-group discussions
16. Demonstrate regular class attendance	Student missed **0–3** classes over the entire semester	Student missed **4–6** classes over the entire semester	Student missed **7** or more classes over the entire semester
17. Demonstrate understanding of key concepts from course through take-home exam (TRIPLE WEIGHT)	Student scored 87–100 %	Student scored 74–86 %	Student scored less than 74%

COURSE GRADE:

Grading: Each objective is worth 5 percent of the course grade, except Objective 12 which is worth 10 percent of the course grade, and Objective 17 which is worth 15 percent of the course grade.

Overall Midterm or Final Grade: ____________________

Learning Objectives Breakdown: ____________________ **High Levels of Mastery**

____________________ **Moderate Levels of Mastery**

____________________ **Low Levels of Mastery**

Assessing Student Performance: Testing

ASSESSING STUDENT learning in biology through paper-and-pencil tests is common practice. Unfortunately, many students learn to dread the test-taking process through their past experiences in biology class. Students are often bombarded with multiple-choice questions that not only stress the factual recall of course-specific vocabulary, but demand that they decipher the sophisticated wording of questions. It is no surprise, then, that students, especially those with learning differences, are often subject to severe testing anxiety that can impinge on their expression of course-specific knowledge (Kovach, Wilgosh, and Stewin 1998).

This section takes a careful look at testing as an assessment tool. We will discuss ways that teachers can construct tests and the test-taking experience so that students can better demonstrate their biology knowledge, be more metacognitive about their approach to tests as a form of assessment, and relieve their test anxiety.

Although tests can sometimes be diagnostic and formative assessment tools, most tests are used as summative assessment tools. Therefore, we will assume for this discussion that tests are being used summatively.

There are four sections that follow:

- Providing Test-Taking Accommodations
- Teaching Test Taking
- Designing and Making Better Tests
- Alternatives to Tests

Providing Test-Taking Accommodations

In order to comply with federal laws, including the Americans with Disabilities Act of 1990 and Section 504 of the Rehabilitation Act of 1973, educational institutions have offered various testing accommodations for students with learning disabilities. The idea behind accommodations is that they attempt to "level the playing field" and to provide a fairer, more accurate assessment of student learning of the material tested. Since most of these accommodation techniques are widely known, we will only briefly mention and discuss them here. All of them require at least some additional logistical planning and support to carry out; however, these efforts should yield more accurate and fair testing results.

Extra Time for Tests

We all process and express written and oral language at different rates. Some students with learning differences process information at a slower-than-average rate. Providing opportunities for extra time to complete tests is therefore helpful for these students. A study completed by S. M. Weaver (2000) compared extended-time test scores of students with learning disabilities with extended-time test scores of students without learning disabilities. The results revealed that students with learning disabilities showed significant gains in test scores over students without learning disabilities under extended-time or untimed testing conditions.

If the purpose of a test is for students to demonstrate their understanding of course concepts, not their speed of information processing, then this is a perfectly appropriate accommodation to offer any student, regardless of whether or not he or she has a documented learning disability. However, legally speaking, this accommodation is required only for students whose documentation supports their specific need for extended time on tests. Often a particular amount of extra time is specified, such as time and a half or two times the regular time allotment.

Alternative Testing Locations

Some students can get distracted or anxious when placed in a large room with other test takers. Providing a quiet, private location may help them perform better in testing situations.

Use of Computers

Sometimes student test performance can be enhanced by providing the opportunity to write answers using a word processing program on a computer. Students with a written-language disability can particularly benefit from this accommodation, although many learners can think more clearly and concisely when composing on a computer.

Test Readers

Difficulty reading test questions is another problem encountered by some students when taking tests. This can be remedied by providing a test reader or proctor who reads the questions aloud. The student can then record his or her responses independently.

Paraphrasing

When requested, teachers can offer paraphrases of particular test questions with complicated wording. An instructor needs to feel comfortable with the amount of information he or she provides students when offering this accommodation.

Oral Test Taking

Some students show weaknesses in expressing their knowledge in writing, whether handwritten or word processed. Offering these students the accommodation of conveying their understanding orally can improve their test performance. This can take place in at least two ways. Students can tape record their answers under a proctor's monitoring, or they can make an appointment directly with the instructor, who can record their responses. This obviously would not be appropriate for an essay exam in which writing organization is being assessed, but could work well for a short-answer format where assessing content knowledge is the goal.

Teaching Test Taking

Since effective test taking is a skill that can be learned, teaching useful test-taking techniques and strategies is another approach to enhancing student performance on tests. There are many resources available on test-taking skills; we recommend Kathleen McWhorter's *College Reading and Study Skills* (2000). It contains chapters on test taking and test preparation. While we do not recommend reorienting a biology class toward comprehensive coverage of test-taking techniques at the expense of biology content and the practice of science, spending some time offering students test-taking tips can have a big pay-off: better student performance on tests. What follows is a sampling of techniques we feel are particularly useful in a biology setting.

Previewing Tests

Suggest to students that before diving in at the beginning and completing a test as fast as possible, they preview the entire test first. Encourage them to look at the different sections of the test and the point allocations, and to skim the questions. This can lessen some of the students' initial feelings of anxiety and help them develop a strategic approach to allocating their time and energy. An instructor should consider previewing the first test of the course with the class to model this strategy.

Start with Strength

Suggest that students first complete a section of the test that they feel the most confident with. For example, if essay writing is a student's strength, then he or she should consider starting there, even though it might be the last section of the test. If the entire test is multiple choice, students could jump around the test, answering the easier questions before attempting the harder ones. Starting with strength builds confidence and can reduce testing anxiety.

Actively Read Test Questions

Active reading means highlighting, circling, or underlining key parts of test questions. Actively reading test questions enables students to break down the task presented to them and keep track of the requested information. Consider the following test question: "Compare Darwin's theory of natural selection with Lamarck's theory of acquired characteristics." In this question, *comparing* is the action, so it is important to highlight it. Additionally, *natural selection* and *acquired characteristics* are items of content that need addressing, so they could be underlined. In another example, "List three features of a prokaryotic cell," circling the word *three* would help a student stay focused on offering the requested number of features.

Proofread When Done

Suggest that students look over the entire test when they think they are done. The purpose is not so much to revisit each question and revise the answers, but to see if all parts of a question have been answered and to determine if directions have been followed carefully.

Build Metacognition into the Test-Taking Experience

After students have finished taking a test, ask them to fill out a test reflection form. An example of a reflection form is shown **in Figure 3.22**.

Provide a Post-Test Analysis Form

A post-test analysis form enables students to analyze a recent test and determine the causes of their errors. An example of such a form is provided **in Figure 3.23**. The form asks students to categorize their test errors in terms of comprehension gaps, Rate the test in terms of its difficulty on a scale of 1 to 5 (1 = very easy, 5 = very difficult).

What grade do you anticipate achieving from this test?

Describe what you think you did well in preparing for the test.

Describe what you think you could improve on when preparing for the next test.

What was the hardest part/section of the test? Why?

What was the easiest part/section of the test? Why?

Figure 3.22. Sample test reflection form

memory difficulties, difficulty with interpreting questions, etc. The idea is that this level of analysis builds students' metacognition skills and encourages them to prevent similar errors when taking future tests.

Designing and Administering Better Tests

This section offers ideas for improving the design and structure of tests. Paying careful attention to how a test is constructed and administered can benefit all learners, especially those with learning differences.

Test Name:

Test Date:

Directions: For each test question where either no credit or partial credit was earned, decide the reason for your error and mark the number of the question in the appropriate row under the Test Question column.

Reason for Error	Test Question
I did not fully understand the concept or information.	
I understood the information, but could not draw it up from memory during the test.	
I did not review/study this information enough in preparing for the test.	
I had difficulty understanding what was being asked for in the test question.	
I did not include enough information in the answer I submitted.	

Figure 3.23. Sample test analysis form

Test Frequency

Instead of giving students one or two exams during a course, consider giving tests more frequently. More frequent testing can lessen the memory and information processing demands on students. They will then be able to focus more on demonstrating their learning of the content than on the strength of their memory. Frequent tests that cover less content can also reduce the anxiety common with tests of huge magnitude.

Link Learning Objectives to the Test

It may seem obvious that testing should relate to learning objectives, but it is a consideration that can be overlooked. What do you want your students to demonstrate to you through the test: Their understanding of the biological content (e.g., the difference between evolution and natural selection)? Are you testing their language skills? their math skills? their scientific thinking skills? their memory for vocabulary? the depth and quality of their reading and note taking? Your responses to these questions should guide the kind of test you design. It is quite possible that a number of these areas comprise your testing objectives. The key is to be sure that the test students take links to the learning objectives you are trying to assess.

Communicate the Learning Objectives Clearly to Students before the Test

Students have a right to know what they are accountable for learning. If you plan to have them demonstrate their skill at drawing conclusions from a data set, it is best for them to know this ahead of time. The easiest way to let students know what they will be accountable for is to give them a list of the learning objectives, or a study guide, at the beginning of a unit or at some other convenient time before a test. We have provided a study guide template (**see page 147**) as well as a sample study guide for a unit test in basic genetics (**see page 148**).

It is also a good practice to let students develop their own study guides based on the reading and activities they have been engaged in. Do not expect students to know how to construct a useful study guide; this technique works best after it has been modeled by the instructor. (**Also see** "Effective Review" **on page 119**.)

Vary Formats within a Test

The standard test formats are multiple choice, true/false, matching, short answer, and essay. Some students will test better on the same content within a multiple choice format; others will test better within an essay format. In order to meet the needs of diverse learners who express their understanding best through different formats, it is important to vary the formats within a test. Include small sections using each of the major format types, and do not structure a test around only one specific format.

Test Practice

Before giving a test, be sure that students have a chance to practice answering the kinds or styles of questions included on the test. It is not effective to design a test entirely of essay questions when matching and multiple choice have been used as the format for review. For example, in advance of a test, provide students with the three essay questions they will be expected to answer. This allows them to organize and rehearse their responses as they prepare for the test.

Students should also be able to practice the kind of thinking required for a test question. For example, if students will be asked on the test to evaluate an experimental design, then give them a review exercise in class that requires them to evaluate experimental designs. If the focus is on recall and basic comprehension of concepts, then allow them time to practice answering questions that demand recall and comprehension.

Student Input

Offer students themselves the chance to construct and submit some or all of the test questions. This can be an effective way to motivate or engage them. It also encourages metacognition as students turn their knowledge into questions. As with a study guide, do not expect students to know how to make good questions. This is a skill that needs modeling, practice, and feedback.

Collaborative Test Taking

Consider offering students the opportunity to collaborate in some way during a test. This collaboration can be as simple as allowing a set, limited time for students to compare and discuss answers with each other. Give them the opportunity to revise their original answers, if they choose to, and submit the revised test. Both an individual and a collaborative component of their grade can be designed if desired. This technique also promotes metacognition and critical thinking as students evaluate the varying answers they encounter in the collaboration.

Provide a Term "Bank"

Consider providing students with a list of all key terms relevant to the test. (This, of course, is most appropriate when term recall is not an assessment goal.) For some students with recall deficits, this technique may help them match a forgotten term name with their accurate conceptual understanding of that term, and thus may offer a fairer assessment of their content knowledge.

Incorporate Multiple Modalities within a Test

The language used by the Center for Applied Special Technology (CAST) for the idea of incorporating multiple modalities in testing is "multiple means of recognition" and "multiple means of expression" (Dolan and Hall 2001). In essence, this means designing and administering tests that allow diverse learners to interpret the test questions and demonstrate their knowledge through their preferred and/or strongest modality.

For example, students with a strong visual preference could be given the option to combine drawing and writing to express an answer instead of just writing it. Similarly, test questions could be created that involve interpreting illustrations. Tactile learners could be offered the use of manipulatives or demonstrations during the testing process, especially the same manipulatives used by the teacher in the instructional process leading up to the test. For example, if pipe cleaners were used to teach about chromosome behavior during mitosis, then have pipe cleaners available for students to handle during the testing process.

Alternatives to Tests

In addition to offering accommodations, teaching test-taking techniques, and designing better, more flexible tests, instructors should consider including alternatives to testing in their assessment of student learning. These alternatives fall primarily under the heading of performance assessments. Some students will never accurately show their mastery of learning objectives through test taking. Therefore, offering these poor testers a chance to show their learning through other means is a viable alternative. The key is finding an alternative that can just as adequately address the learning objectives under study. What follows are some examples of these alternatives.

Model Building

Have students build models that demonstrate the key concepts, terms, and relationships studied in a particular unit. Some appropriate applications would be an ecosystem or a cell. Giving students adequate time and careful, explicit guidelines is critical for the success of this unique means of assessment.

Posters or Other Forms of Presentations

Have students design posters that include the key concepts, terms, and relationships studied in a particular unit. The posters could be combined with an oral presentation. A poster articulating the theory of natural selection could combine Darwin's ideas with photos, text, and colorful graphics that show the thinking and applications behind this central biological topic. Alternatively, ask students to make a PowerPoint presentation to the class. For more on poster presentations, see "Assessing Student Performance: Poster Presentations" **on page 151**.

Formal Debates

Have students prepare for and engage in a debate that synthesizes their learning in a topic area. Possible topics that require students to synthesize essential biological content are genetic engineering, evolution vs. creationist science, and habitat preservation controversies (Everglades, tropical rainforests).

Concept Maps

Concept maps can be an excellent alternative to a paper-and-pencil test. A unit-level concept map assignment would require strong synthesizing skills that would clearly show the depth of a student's content understanding. For this alternative to be successful, students would have to be familiar with making concept maps. It is important not to test them on their understanding of concept mapping, but on their mastery of the content learning objectives. See the section on concept maps beginning **on page 90** for more information.

Miscellaneous Alternative Forms of Assessment

Letters to members of Congress or town officials, poems, dances, skits, pamphlets, or student-made videos or Web sites can also be useful alternatives to tests.

References

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McWhorter, K. 2000. *College reading and study skills*, 8th ed. New York: Harper Collins.

Weaver, S. M. 2000. The efficacy of extended time on tests for postsecondary students with learning disabilities. *Learning Disabilities* 10:47–56.

STUDY GUIDE TEMPLATE

Test Date:

Scope of Test:
What the test (or quiz, or other assessment) covers in terms of chapters in the text, lecture dates, and other resources (such as worksheets, videos, Web pages, CD-ROMS, etc.) that students might find helpful as they prepare for the test.

Course Grade Weight:
What percentage of the course grade is this test or assessment worth?

What to Bring to the Test:
Note here any aids students may bring to the test (such as a calculator and any notes which may be allowed) and specify particular things they may not bring (for example, "This is a closed-book test").

Format:
Include types of questions and approximate number and point value of each type.

Vocabulary and Concepts:
List vocabulary terms and concepts to be tested.

Test Expectations:
Include here what students are expected to be able to do.

Take-Home Component:
A take-home component is optional. It may include essays which students may prepare and turn in separately, or essays which will be on the test and are given to students in advance for study purposes, but which they are not to write outside of the test period.

Getting Help:
Include here any extra office hours, T.A. hours, review sessions, etc.

SAMPLE STUDY GUIDE

Test on Genetics

Test Date: April 23, 2003

Scope of Test: Covers material from chapters 6 and 7, class dates 3/31–4/21. Other important materials: Video "Mitosis and Genetics"; Mendelian genetics worksheets.

Course Grade Weight: This is test 3 of 4. It is a 100-point test, worth 10% of your grade.

What to Bring to the Test: You may bring one sheet of paper (8½ x 11) with notes (one side only) to the test. No magnifiers allowed! You must make up your sheet yourself. Do not simply photocopy material from the book. If you attempt to include all the information from these chapters on one sheet, you will spend more time looking for information than you do working on the test. In addition, you may bring an outline of each essay (see below) if you have chosen not to write them ahead.

Format:
The test will have four parts:

- Multiple choice—2 points each; about 10 questions
- Short answer/fill-in-the-blank—3 to 7 points each; about 10 questions
- Describe, draw, or demonstrate with clay the process of meiosis; 10 points
- Essays—two questions; 10 points each

Vocabulary and Concepts:

- cell cycle
  - — G1 phase
  - — S phase
  - — G2 phase
  - — M phase
- interphase
- chromatin
- chromosome
- replication
- sister chromatid
- centromere
- condensation
- supercoil
- mitosis
  - — prophase
  - — metaphase
  - — anaphase
  - — telophase
  - — cytokinesis
- spindle fibers
- cleavage furrow
- daughter cells
- somatic cell
- germ-line cell
- gamete
- zygote
- fertilization

- diploid
- haploid
- homologous chromosomes
- reduction division
- meiosis I
  - — prophase I
    - ◊ crossing over
  - — metaphase I
  - — anaphase I
  - — telophase I
- meiosis II
  - — prophase II
  - — metaphase II
  - — anaphase II
  - — telophase II
- heredity
- true-breeding
- P generation
- F1 generation
- dominant
- recessive
- gene(s)
- homozygous
- heterozygous
- hybrid
- allele(s)
- phenotype
- genotype
- Punnett square
- test cross
- monohybrid cross
- chromosome
- zygote
- gamete
- sperm
- egg
- pollen
- ovule
- incomplete dominance
- continuous variation
- polygenic
- monogenic
- X chromosome
- Y chromosome

Test Expectations:
You should be able to:

- Label and order the stages of mitosis
- Compare and contrast mitosis and meiosis and identify the purpose of each
- Explain the connection between genotype and phenotype
- Predict phenotype from a given genotype
- Use Punnett squares to predict the probable genotypes and phenotypes of a given cross
- Plan a cross to determine the genotype of a given individual
- Relate meiosis to genetics
- Explain how traits can “skip generations”
- Discuss variations from Mendel’s laws

Take-Home Component:
The essays for this exam:
Choose two of the three to answer.

1. Compare and contrast mitosis and meiosis. Describe the function of each, as well as of the processes themselves.
2. Mendel's laws do not explain all the traits we see or the inheritance of those traits. Discuss variations from Mendel's laws. Include at least three inheritance mechanisms that vary from Mendel's observations. How does each variation work?
3. Suppose you identify a new gene in mice. One of its alleles specifies white fur color. A second allele specifies brown fur color. You are asked to determine whether the relationship between the two alleles is one of simple dominance or incomplete dominance. What sorts of genetic crosses would give you the answer? Be specific. On what types of observations would you base your conclusions? (From C. Starr and R. Tagart, *Biology: The Unity and Diversity of Life,* 10th ed. Belmont, CA: Thomson Learning.)

You may bring an outline for each essay to the exam, or you may write the essays ahead of time and turn them in with your exam.

Getting Help:
Extended office hours: I will be available in my office from 12 to 1:30 p.m. Tuesday, 4/15, Tuesday, 4/22, and Thursday, 4/17.

Review session: In class, Monday, 4/21.

Science Coursework support hours: Wednesdays, 6–7 p.m., in the Coursework Support Center.

E-mail: instructor@yourcollege.edu

Assessing Student Performance: Poster Presentations

Background

One type of performance-based assessment is a poster presentation. A poster is a large visual display of information on a specific topic. Important information is enhanced with diagrams, pictures, color, and other eye-catching techniques. Verbal information is distilled to the most important main ideas, details, and explanations. Figure 3.24 shows a student-made poster. The poster is introduced to

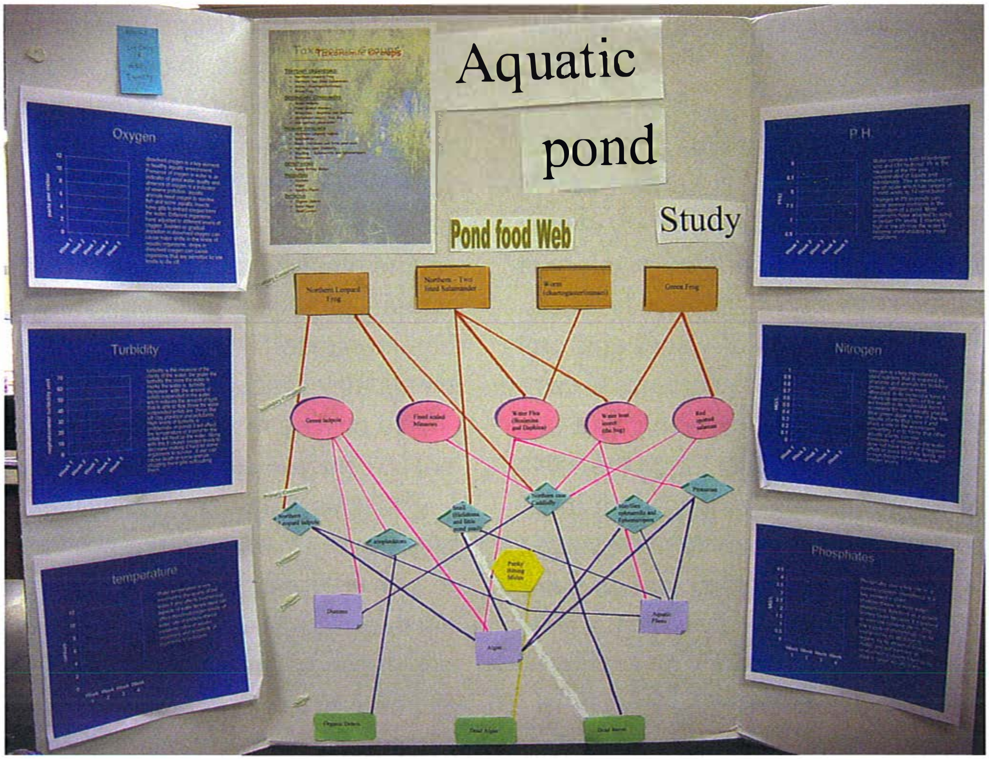

Figure 3.24. An example of a student poster

the students as a vehicle designed specifically to convey information in a visually efficient manner. Its goal is to provide as much information as possible to many individuals in a relatively short time period (minutes). Poster sessions are regularly held as part of scientific conferences to provide an efficient venue for sharing information rapidly with colleagues.

Student posters can be displayed at an informal poster session. For example, several science classes might host a poster session to share the results of individual student projects with members of several classes. Poster sessions may be open to the public; consequently, more people are exposed to the information, and students have the opportunity to discuss their work with larger, often lay, audiences. Also, the poster session can be useful in highlighting activities and achievements of the biology department.

Rationale

There are several advantages to creating a poster session with students.

- A poster session allows students to present a topic of personal interest to a larger community. They experience both the public display of their work and a demonstration of their mastery of the material by explaining their topics to others.
- Additionally, these modes of visual and oral presentation underscore the importance of communication in the sciences. Poster projects can be used as a tool to explicitly teach the skills necessary for completion of long-term independent projects; students can be assessed on process skills such as developing a thesis statement or hypothesis, creating a working outline, conducting background research, and completing work by specific deadlines.
- Posters also aid students' learning by encouraging them to research areas of their personal interest and by providing a different format for them to display their knowledge. Having students choose their own topics allows them to delve more deeply (in a structured manner) into a concept that has been mentioned briefly in class or that falls outside the scope of course material.
- Most importantly, poster projects give students practice in approaching a project from their specific strengths.

Process

Student posters may be approached from two different starting points. In one type of poster, the *information synthesis* poster, the students present topics on which they have done background research. This form of poster can be used to help students develop skill in gathering and assembling information from a variety of sources. From the teacher's perspective, this type of poster can provide a means of encouraging higher level, analytical thought. For example, students researching controversial topics, such as stem-cell research or genetically modified crops, can be asked to synthesize information on both sides of the issue and support their conclusions about the safety or ethics involved.

The other type of poster, the *original research poster*, provides an opportunity for students to communicate the results of one or more experiments they conducted using the scientific method. These posters more closely resemble those at scientific conferences.

Poster sessions may also be used to enhance oral presentation skills or to improve the sharing of information with peers in a large classroom setting. Students can be asked to provide a two- to five-minute orientation to their poster before allowing the class to freely circulate. The use of large self-adhesive (Post-It–style) poster paper or an easel allows for easy movement of posters from the front of the classroom for the oral portion of the presentation to a different site for individual viewing.

Instructors can introduce various strategies to promote peer review of posters. Critique forms can be developed and provided which require all students to view each others' posters. Alternatively, students may be provided with the same rubric that the instructor will use to evaluate the posters. These forms can be graded, reinforcing the value of constructive peer review in the sharing of scientific information.

Useful Strategies for Assigning Poster Projects

- Determine exactly what your goals for the project are. Examples: Are you specifically interested in having students complete original research? Do you have a general topic in mind that you'd like students to explore further?
- When the project is first assigned, give students a worksheet that explicitly states the learning objectives and expectations for the project. Include process deadlines, such as due dates for thesis/hypothesis statements, working outlines, and draft models of the poster. Also include expectations for source materials (what types and how many).
- Give students a grading rubric for the poster early in the process; it is essential that students be aware of exactly how they are being evaluated *while* they develop their posters. **See page 154** for an example of a rubric for a poster presentation.
- Provide qualitative feedback at several stages in the poster-making process.
- Involve other faculty in the poster session by having them visit student posters and ask relevant questions, so the students have the opportunity to explain their understanding to someone other than the classroom teacher.
- Allow students time to visit classmates' posters.
- Plan a wrap-up discussion after the poster session, so students can reflect on the entire process and on the poster session itself, or distribute a written reflection form for students to complete.

AN EXAMPLE OF A POSTER PRESENTATION ASSESSMENT RUBRIC

Broad Area of Assessment	Specific Area of Assessment	Qualities of Excellent Work (full credit)	Qualities of Developing Work (partial credit)	Qualities of Incomplete Work (no credit)	Comments/Points
Content (65 points)	Abstract (5 points)	Provides a concise summary of the entire project in one paragraph	Is missing some essential information about the scope of the project	Missing, or so brief as to be irrelevant	
	Experimental Question (5 points)	Clearly articulated	Present, but is somewhat confusing or misleading	Missing or completely misleading	
	Background Info (10 points)	Shows strong evidence of completion and understanding of background research on the topic	Shows little evidence of completion and understanding of background research on the topic	Missing, or extremely brief	
	Hypothesis/ Predictions (5 points)	Clearly articulated; shows what you expected and why you expected it	Present, but confusing, misleading, or lacking some depth	Missing, or irrelevant to research	
	Procedure (10 points)	Described in enough detail to show clear idea of experimental design; explicitly lists dependent and independent variables	Missing some detail that is important to understanding experimental design; misidentifies dependent and independent variables	Missing or extremely brief	
	Data (tables and graphs) (10 points)	Appropriately titled, labeled, and easy to read and interpret	Some data missing, or titles lacking or confusing to interpret	Missing or undecipherable	
	Written Results (5 points)	Clearly and completely describes the most important results shown in the data; avoids interpretation; contains just the facts	Describes some but not all of the important results from the data, may include some interpretation not appropriate for this section	Missing or extremely brief	

Broad Area of Assessment	Specific Area of Assessment	Qualities of Excellent Work (full credit)	Qualities of Developing Work (partial credit)	Qualities of Incomplete Work (no credit)	Comments/Points
	Conclusions (10 points)	Fit the data shown, relate directly to the hypothesis/predictions and, if appropriate, updates thinking about hypothesis	Some aspects do not fit data; missing some connections to hypothesis; update in thinking lacking	Missing, or extremely brief or irrelevant	
	Bibliography (5 points)	Present and contains usable references to sources used for project	Present, but the references are not complete or usable	Missing or undecipherable	
Poster Design (25 points)	Title (5 points)	Present and easy to identify	Present, but not prominent enough	Missing	
	Visual Appeal (10 points)	Neat, readable, proper point size for text, balanced mix of text and graphics	Lacking neatness; font/point size make poster hard to read; not a good balance of text and graphics	Poster impossible to interpret based on layout	
	Organization (10 points)	Sequenced in a logical way; easy to identify the main ideas of project	Confusing sequence; hard to identify some main ideas of project	Poster impossible to interpret based on layout	
Interview (10 points)	Interview with Science Faculty (10 points)	Shows command of the topic/research; able to answer or consider adequately the interviewer's questions	Shows **some** difficulty in discussing certain aspects of project or in addressing interviewer's questions	Shows **considerable** difficulty with discussing the poster and project as a whole	

Overall Grade/Comments:

The Biology Laboratory

Why Biology Laboratories Are Important

Most introductory biology courses in high school and college contain a laboratory component, a time when students characteristically engage in activities that are "hands on" in nature. Labs may take many forms, but their presence in a biology course is considered essential to the learning of biology. There are a number of pedagogical reasons for requiring that students get some form of laboratory experience in biology.

Most biology instructors would say that labs provide an opportunity for students to see a concrete demonstration of various biological phenomena that would be difficult to replicate in a "lecture" context. In addition, laboratory experiences teach the use of equipment and techniques that are key to further biological studies. Labs also provide a glimpse into how real-world scientists conduct their work, with the intention of inspiring an appreciation for the work of a professional scientist. Many would claim that the lab offers an excellent opportunity for students to practice the gamut of scientific thinking skills, from observation to hypothesis generation to drawing conclusions based on data. And, of course, there are the basic claims that doing laboratory science is simply fun and engaging for students of all backgrounds and interests, and that it draws out the innate scientific curiosity in all of us (Sundberg et al. 2000). For all of these reasons, the biology laboratory is an indispensable element of any student's educational experience.

Types of Biology Laboratories

For this manual's purposes, two basic types of biology laboratories will be examined: *demonstration* laboratories and *inquiry-based* laboratories.

Demonstration Labs

Demonstration labs, often referred to as "cookbook" labs, typically involve a highly structured laboratory setting in which students follow a set of instructions that lead them to some predetermined outcome, usually to show a biological phenomenon.

For example, students may obtain and view a set of animal cells (such as human cheek cells), and obtain and view a set of plant cells (such as *Elodea* cells), then draw and compare what they observe. They may be instructed how to obtain the cells and what to look for under the microscope. The result of this activity is a confirmation of what they (and their instructor) already know from their biology lecture, textbook reading, or previous experience: plant cells and animal cells are different in some fundamental ways.

Another example might be asking students to follow a series of steps in which they add chemicals to a substance to show the breakdown of starch by the amylase enzyme. The students get to witness the activity of a key biological agent. Usually a demonstration lab ends after the teacher gives the students some directed questions about what they observed.

Inquiry-Based Labs

Inquiry-based labs ask that students take a more active role in practicing the thinking processes scientists use to investigate the natural world. This means that students are expected to do some or all of the following: ask questions; develop and test hypotheses; design careful scientific procedures; record and represent data; and draw, communicate, and defend conclusions. For example, an instructor might ask students how they would determine if the cells of plants, animals, protists, bacteria, and fungi are of similar size and structure. In order to answer this question, students would have to design and follow a procedure, gather materials, and make careful observations to draw their conclusions. This would require much more student responsibility and thinking than a typical demonstration lab.

Inquiry-based biology laboratories can be placed along an *inquiry continuum,* as shown in Figure 3.25, from *structured inquiry* to *guided inquiry* to *open-ended student inquiry* (NREL1999). *Structured inquiry* describes an activity in which the instructor offers explicit instructions and procedures, yet students are pressed to draw their own conclusions. *Guided inquiry* describes an activity in which the instructor supplies the investigative question and perhaps the materials to use, while the students follow a procedure of their own design and draw the subsequent conclusions. Finally, *open-ended student inquiry* requires the most independence, because students generate their own questions, procedures, etc. from a topic chosen by the instructor or by themselves. It is important to note that the categories on the continuum are generalized; most biology labs cannot be rigidly placed in any one category and may fall in between the categories.

Demonstration vs. Inquiry-Based Labs—Advantages and Disadvantages

Most scientific and scientific education organizations strongly advocate the inquiry-based teaching

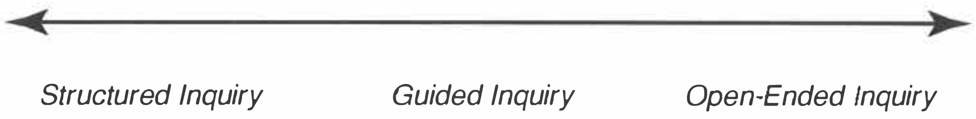

Figure 3.25. The inquiry continuum

approach to the biology laboratory (NSF 1996; NRC 1996). The claim is that inquiry-based approaches are more student-centered, inspire more active and creative learning, and cultivate stronger problem solving abilities in students; and that demonstration labs encourage passive learning and do not challenge students to think scientifically or engage students' higher-order thinking skills.

There are situations, however, where a demonstration lab is an essential instructional technique in a biology course. Demonstrations may show or reinforce a phenomenon effectively and efficiently. Demonstrations can also teach students laboratory skills and techniques, such as microscopy or pipetting, that will serve them as they pursue their study of biology. Time or materials limitations may also require that an instructor employ demonstrations instead of inquiries.

There are critics of inquiry-based approaches as well. They claim that this approach takes longer, demands much more from the instructor (as well as the student), and places too much emphasis on process, with the consequence that students either do not learn the appropriate content or misunderstand the content's relevance to the inquiry.

The authors of this manual submit that there are situations in which a demonstration lab may be appropriate and others in which an inquiry-based lab may be appropriate. However, edging the student's biological laboratory experience toward the right end of the inquiry continuum is a worthy and pedagogically sound goal.

While less-structured inquiry labs may be a desirable goal, research and Landmark College faculty experience have indicated that structured or guided inquiry labs are the most effective for students with learning disabilities—as they are for many students without learning disabilities (NREL 1999). Students with learning disabilities tend not to possess the skills necessary to deal with the cognitive and procedural demands of open-ended inquiry experiences. Thus, the lab materials contained in this manual are primarily for structured or guided inquiry. Over the course of a semester, instructors may be able to move students toward the right side of the inquiry continuum, to less-structured experiences. For any particular lab, the instructor can also be flexible in determining how much structure the class as a whole or individual students need, and can make appropriate accommodations.

Common Biology Lab Difficulties for Students with Learning Disabilities

Any biology laboratory approach may be problematic for students with learning disabilities. Such students tend to have difficulties comprehending, making predictions, sequencing, prioritizing information, creating quantitative visual displays (such as graphs or charts), and drawing conclusions (NREL 1999). The following list elaborates on each of these areas of difficulty.

Comprehension:

- Understanding the wording of a procedural step
- Knowing what variables are or how they fit into an experiment
- Processing oral instructions
- Selecting the proper equipment needed
- Knowing the precise meaning of hypothesis, conclusion, etc.

Making Predictions:

- Creating a relevant hypothesis
- Making a prediction that is a testable hypothesis

Sequencing:

- Following the sequence of steps in a procedure without skipping steps
- Creating and organizing a logical progression of steps when designing a procedure

Prioritizing Information:

- Organizing data
- Identifying key data needed to draw appropriate conclusions
- Identifying the key information needed to evaluate or revise a hypothesis

Making and Understanding Visual Displays:

- Putting data into graphic form
- Interpreting visual organization
- Writing descriptions of the data from graphical forms
- Identifying similarities or differences when comparing graphs

Drawing Conclusions:

- Drawing appropriate conclusions that follow from the results
- Identifying sources of error
- Identifying underlying assumptions that govern the lab
- Relating the results to new situations

Given that students may struggle with the various areas of scientific inquiry just outlined, instructors must recognize that individual steps of the scientific inquiry process may need to be taught separately and explicitly. Doing so will help lay the groundwork for success as students are presented with laboratory tasks that tend more toward the "open-ended" side of the inquiry continuum.

Adapting Labs to Make Inquiry-Based Learning Work for Students with Learning Disabilities

The following set of ideas may be helpful in promoting student success with inquiry-based activities.

Start with the Familiar

To introduce students to the process of inquiry, take them through an engaging activity that shows that inquiry thinking is natural and normal. For example, pose the question or challenge "What is the fastest way to make packing-peanuts dissolve?" (assuming the use of cellulose-based biodegradable packing-peanuts). Provide students with the materials (various solutions, such as vinegar, hot water, ice water, soap, salt, heat sources, etc.) and some boundaries (e.g., time and safety), and let them loose. After the experience, share results and introduce some of the terms related to scientific method or inquiry thinking embedded within the task.

Isolate and Teach the Steps of Inquiry

It may help students if an instructor breaks down the inquiry process into its components and teaches each in isolation before expecting students to put all the steps together. For example, teachers should model how to generate testable questions and should provide students the opportunity to practice developing their own. Likewise, spending some class time modeling and discussing hypothesis making, followed by creating and comparing student-generated hypotheses, would foster greater student competence with this skill. Teach other inquiry skills, such as the characteristics of a good experimental procedure (replication, avoiding bias, controlling variables, etc.). Three activities contained in this manual are designed to teach students the skills necessary to engage in scientific inquiry: “Developing Hypotheses” beginning **on page 193**, “Designing Controlled Experiments” beginning **on page 195**, and “Graphing Data” beginning **on page 198**.

Provide and Use Templates

A template shows a pattern or blueprint for following a process. It can be made in three different formats: a text-only format, a graphics-only format, or an integrated text and graphics format. Templates help make abstract thinking or writing structures concrete and visual. They also aid students in discerning and applying the steps of a complex procedure such as the scientific method. With repeated use and practice, students can internalize a template and eventually work without it. We have included two examples of templates applicable to inquiry-based lab activities in biology: a Worksheet for Designing Controlled Experiments **in Appendix C** and a Lab Report Template **on page 163**.

Start with Small Changes to Existing Labs

If it feels overwhelming for an instructor (and students) to modify existing demonstration labs to involve more inquiry, take an incremental approach. Choose an existing lab and consider where it might be possible to change one aspect of the lab toward greater inquiry. Emphasize only that one particular inquiry skill for that lab.

For instance, a lab could be adapted so that students are asked to come up with their own hypotheses, yet still follow a strict procedure guided by the instructor for carrying out experiments. For another lab, allow students to design their own data table instead of using a preexisting table. In another lab’s conclusion/discussion section, assign students to find previously published research that supports their conclusion.

The set of osmosis activities starting **on page 286** provides one example of how a lab can be modified to allow for more student inquiry. We have included a demonstration osmosis activity, a structured inquiry osmosis activity, and a guided inquiry activity. While each activity uses the same phenomena and materials, the students’ role and level of inquiry differs.

Consult with Other Professionals and Professional Resources

- Ask other colleagues if they have versions of labs that reinforce the same content and concepts but are more inquiry-based.
- The following periodicals all offer ideas for adapting the biology curriculum toward greater inquiry:
  —*The American Biology Teacher* (published by the National Association of Biology Teachers, 12030 Sunrise Valley Drive, Suite 110, Reston, VA 20191. 800-406-0775. www.nabt.org)
  —*The Journal of College Science Teaching* and *The Science Teacher* (both published by the National Science Teachers Association, 1840 Wilson Boulevard, Arlington, VA 22201-3000. www.nsta.org)
- Web sites such as Access Excellence (www.accessexcellence.org/) can offer an abundance of teaching ideas, many of them inquiry-based.

Long-Term Labs

Many science teachers value the idea of having students learn science through a long-term inquiry-based research project. Long-term projects, such as the “Fast Plants” activity **on page 217**, offer additional benefits and challenges to students with learning disabilities that may not be found in one-day or short-term labs. A long-term project gives students who have difficulty mastering lab skills time to practice and become proficient in those skills. Spending short periods of time on the project within longer class periods breaks up each class into more digestible units, which is helpful for students with attention deficit issues. Long-term projects also allow the instructor to take time periodically throughout the project to explicitly teach the inquiry and lab skills necessary to complete each component of the lab. This provides tremendous support and insures success for all students.

The challenges long-term labs present must also be considered. Students can feel overwhelmed with such a large task looming, so it is imperative for the instructor to set manageable timelines and provide organizational tools to help. For example, a graphic organizer that allows students to plan short-term and long-term tasks can be an essential aid. (**See page 222** for an example of a long-term project planner.) As many different skills are required to complete a long-term project, the skills necessary for each project should be taught explicitly. (For an example of teaching graphing skills explicitly, see the "Graphing Data" activity **on page 198**.)

Often, long-term projects count quite a bit toward a final course grade. Consequently, it is important to assess student progress carefully. Ongoing formative assessment practices during the project are essential for students who may have difficulty pulling a project together at the end, or who have attendance issues that cause them to miss some pieces along the way. We've included examples of both formative and summative assessments that value process as well as the final product in the "Fast Plants" activity starting **on page 217**.

Because long-term projects offer benefits to students that are not easily achieved in one-day or short-term labs, instructors should address potential challenges in a proactive manner to allow incorporation of this useful pedagogical tool in the classroom.

Conclusion

There is no denying that modifying biology labs toward greater inquiry takes time for the instructor. Students, especially those with learning disabilities, may find the inquiry process frustrating and difficult at first. However, if the proper structures and strategies are built into a course, an inquiry-based laboratory approach can produce improved learning of biology content and better scientific thinking skills.

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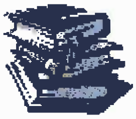
LAB REPORT TEMPLATE

Title:

→ Answers the question, “What is the **topic** of this experiment?”

Introduction:

Background:



Specific Question Being Addressed:

→ Introduces reader to the **background information necessary to understand the experiment;** may include key terms, concepts, and previous research findings; and orients the reader to the **specific research question** you are addressing with this experiment.

Working Hypothesis and Predictions:

→ **The hypothesis MUST be stated as a complete sentence,** usually in an “if–then” format. It should also contain your predictions about how the experiment will turn out.

Procedure:

Materials:

Methods:

→ The “Materials” section lists the **equipment and supplies** that you used for the experiment.

The “Methods” section provides the **series of steps** you followed to perform the experiment. *These steps should be detailed enough that your reader could recreate your experiment based only on the information listed here!*

Results:

Written:

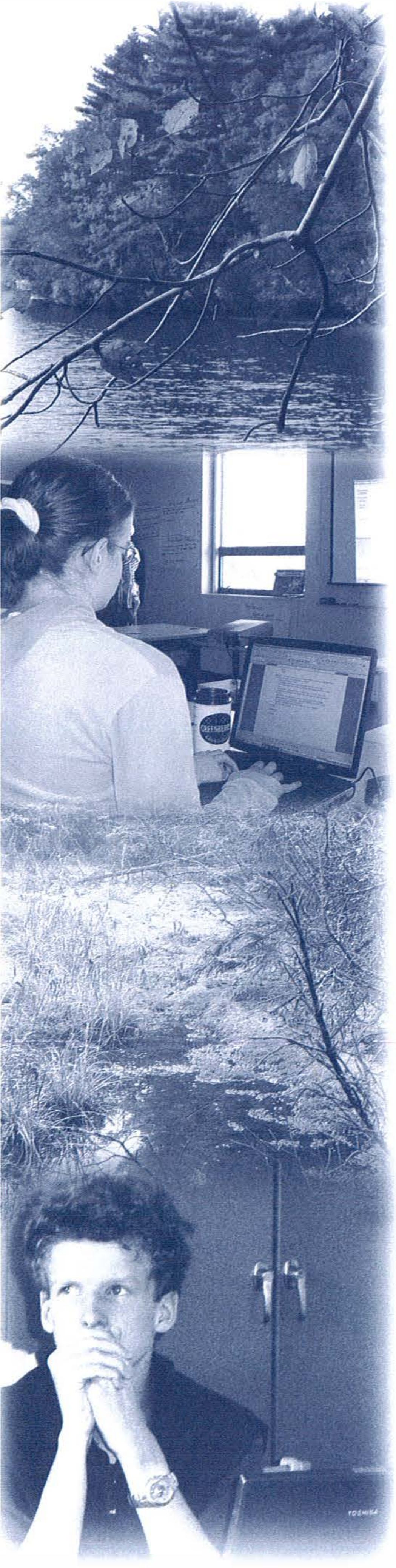
Visual:

→ The results of your experiments are summarized here, usually in both a **written summary** and a **visual summary**. The visual summary, generally in the form of **diagrams, graphs, and/or tables** of data, is very important in helping the reader understand the results of your experiment. *Do not discuss the implications of your data here; this section is “just the facts”*!

Discussion:

→ There are several key features to the discussion section:

1. It summarizes the significant implications of the experiment.
2. It compares the actual results of the experiment to the predicted results of the hypothesis, and includes a revision of the hypothesis, if appropriate.
3. It includes a **metacognitive** component, which may address the following questions: *“How might this experiment be improved?” “What directions might this research take from here?” “What sources of error might there have been?”*



4 USING THE INTERNET AND CD-ROMS IN THE BIOLOGY CURRICULUM

Introduction

The powerful learning potential of the Internet, CD-ROMs, and other digital media has led to a gradual shift in how biology is taught and learned in the contemporary high school or college classroom. Yet these potentially significant learning tools can present unique teaching and learning challenges, especially for students who learn differently. In this section we present an annotated list of Web sites that the authors believe are effective at meeting the needs of diverse learners while offering high-quality science content.

All Web sites were examined for their accessibility for students with specific issues in four primary categories: (1) reading, decoding, and vision; (2) considerations when using a screen reader (**see page 76** for more on screen readers); (3) distractibility, short-term memory, and attention; and (4) content comprehension. Each site described in the annotated list scored consistently high in each of these categories. The sites were evaluated by instructors and students at Landmark College and at Keene State College in Keene, New Hampshire.

The annotated list gives each Web site's URL and title followed by the review. The review includes the name of the site's host along with some notes on its content. Since the intent of these reviews was to discuss how the sites can meet the needs of diverse learners and not to demonstrate the quality of their content, the content section is limited to a general overview. Also included are "Design Notes." These are comments regarding the Web site's layout, structure, and technological requirements, such as any additional software or plug-ins required. Also noted is whether the site meets the basic requirements to be viewed and read by a screen reader, based on the presence of "alt" tags (HTML code that provides a brief description of an image, thus allowing the viewer to hear a description of the image if a screen reader is employed). The sites are listed in no particular order.

Following the annotated Web site list are a brief discussion of "CD-ROMs and Diverse Learners" and the two evaluation forms used to examine the Web sites and CD-ROMs.

Web Sites Recommended for Diverse Learners

http://www.cellsalive.com
(Cells Alive!)

Site Content: The Cells Alive! site contains computer-enhanced images and animations of living cells and organisms that can be studied and used by teachers and students in the classroom. Some of the animations are available for free, and others for a fee. Several interactive activities are available on the site, which is hosted and created by an individual, James A. Sullivan, with no organizational affiliation.

Design Notes: The site employs Flash animation to depict various concepts, so the Flash plug-in is needed to take advantage of these animations. Some of the images on the site contain "alt" tags; however, the "alt" text does not adequately inform the viewer of what the image is.

http://www.ornl.gov/TechResources/Human_Genome/home.html
(Human Genome Project)

Site Content: This is a comprehensive site about the Human Genome Project funded by the U.S. Department of Energy. The site includes topics ranging from current news about the project to research updates to ethical, legal, and social issues to chromosome images, and much more.

Design Notes: This site employs Flash, Media Player, and RealPlayer for some of its multimedia elements; however, much of the site requires no additional software. The site is actually a suite of sites related to the human genome, so there is no consistency in either design look or navigation throughout all the pages within the suite. This has the potential to cause difficulty with navigation. Since the number of linked sites included is so large and comprehensive, instructors are advised to preview the site and send students to a particular linked page rather than to the home page.

http://www.life.umd.edu/CBMG/faculty/wolniak/wolniakmitosis.html (Life Sciences: Introduction to Mitosis)

Site Content: This site provides descriptions and photographs of mitosis occurring in a stamen hair cell of the spiderwort plant. Each photograph has a time stamp on it; thus, the viewer can get a sense of how long each step actually takes. The site is hosted at the University of Maryland by Professor Stephen Wolniak, Department of Cell Biology & Molecular Genetics.

Design Notes: The site images are photographs that can be viewed with a browser only; the site contains no animation, nor does it require additional software to view. The navigation is straightforward and easy to use. The mitosis images do not contain "alt" tags.

http://www.pbs.org/wgbh/aso/tryit/evolution/ (A Science Odyssey: You Try It: Human Evolution)

Site Content: This Web site is hosted by WGBH-TV, a public television station in Boston. It shows the major hominid species that have been discovered thus far, when they lived, and how they may have been related to each other.

Design Notes: This site is available in two versions, one that requires Shockwave and one that is text based. Both sites contain the same content; the only difference is in the presentation. "Alt" tags are consistently used in the text-based version. Navigation is clear and straightforward.

http://www.pbs.org/wgbh/nova/photo51/ (Secret of Photo 51)

Site Content: This site is a companion to a PBS documentary, *The Secret of Photo 51,* about the work of Rosalyn Franklin. It is not necessary to watch the video to reap the benefits of the Web site. There are several articles as well as three interactive pieces available. The first interactive section is a slide show of the "molecules of life"; the second is an in-depth examination titled "Anatomy of Photo 51"; and the third section, "Journey into DNA," is an animation that allows viewers to progress into a cell's DNA down to the molecular level.

Design Notes: "Journey into DNA" comes in both a Flash and a non-Flash version. "Anatomy of Photo 51" is available only in a Flash version. "Alt" tags are used consistently throughout the site, and the text included in them is informative.

http://tolweb.org/tree/phylogeny.html (Tree of Life Web Project)

Site Content: This gigantic site contains information on the phylogeny, taxonomy, and biodiversity of organisms. Each page contains information about one group of organisms. Because the site is so large, it is recommended that students be given a specific page or section to visit, rather than being assigned open-ended browsing. The site represents a collaboration among over 200 authors; the material on the site has gone through a peer review process before being included.

Design Notes: Navigation on this site follows a hierarchical pattern, allowing a visitor to progress down a specific path about a species. This makes it difficult to change direction in the middle without returning to pages already visited. Although the site uses "alt" tags throughout, the text does not adequately describe the intended images.

http://www.ucsusa.org/
(Union of Concerned Scientists)

Site Content: This site has information on the issues of concern to the Union of Concerned Scientists. A small sampling of topics includes global warming, antibiotic resistance, invasive species, and biotechnology. Also included are curricular materials available to teachers. A note of caution: The site is a venue for the UCS to showcase its philosophies, which may be interpreted as biased. There are also several places where a visitor can "take action" and send a prewritten letter (which can be changed) to various organizations and individuals.

Design Notes: Some pop-up windows are used on the site for more information about a particular topic. Use of "alt" tags is inconsistent throughout the site. RealOne Player is required to view some animations.

http://www.lbl.gov/Education/ELSI/ELSI.html
(ELSI—Ethical, Legal and Social Issues in Science)

Site Content: This site is hosted by the Lawrence Berkeley National Laboratory and primarily provides information on the ethical, legal, and social implications of selected areas of scientific research. Six specific areas (Basic and Applied Research; Breast Cancer Screening; Science, Ethics and Democracy; Indoor and Outdoor Air Pollution; Genetic Patents and Intellectual Property; Personal Privacy and Medical Databases; and Sustainable Development) can be investigated, each one launching its own Web site.

Design Notes: Each individual topic launches a new Web site. Most use frames, yet one (Science, Ethics and Democracy) goes to a *New York Times* article on the topic. There are no "alt" tags used on any of the sites except the first page.

http://ublib.buffalo.edu/libraries/projects/cases/ubcase.htm
(Case Studies in Science)

Site Content: This site is hosted by the State University of New York at Buffalo and provides a collection of case studies that can be incorporated into the biology curriculum. Case studies included are arranged in the following topic areas: Anatomy & Physiology; Anthropology; Astronomy; Chemistry/Biochemistry; Computer Science; Ecology/Environment; Evolutionary Biology; Food Science; General Cases; Geology; Mathematics/Statistics; Medicine/Health; Microbiology; Molecular Biology/Genetics; Nutrition; Pharmacy; Physics/Engineering; Plant Science; Psychology; and Teaching Cases.

Design Notes: "Alt" tag use is intermittent on the site, with some case studies using tags consistently and others not at all. The navigation of all sites is fairly consistent throughout, with few links from each page.

http://gslc.genetics.utah.edu/
(Genetic Science Learning Center)

Site Content: The University of Utah Genetic Science Learning Center at the Eccles Institute of Human Genetics hosts this site as a way to distribute its genetics curriulum materials. The content on the site is extensive, ranging from the basics of DNA to genetic disorders to cloning to genetic engineering, with many additional topics in between.

The site includes activities and exercises for students, as well as materials for teachers and suggestions on how to use the site.

Design Notes: The site is cleanly designed, with clear and consistent navigation throughout. Some of the animations require Flash software to run. There is inconsistent use of "alt" tags on the site.

http://www.dnaftb.org/
(DNA from the Beginning)

Site Content: Hosted by Cold Spring Harbor Laboratory, this site contains a plethora of information on genetics. The site is divided into three main sections: Classical Genetics; Molecules of Genetics; and Genetic Organization and Control. Each page provides links to multimedia that support the concepts on that page.

Design Notes: Flash animation, RealPlayer, and JavaScript are employed for various aspects of the site. Some "alt" tags are present, but many of the images are in Flash format.

http://www.biology.arizona.edu/
(The Biology Project)

Site Content: The Biology Project is run by the University of Arizona and is home to a great number of problem sets and tutorials on the following subjects: cellular biology; biochemistry; chemicals and human health; developmental biology; human biology; immunology; Mendelian genetics; and molecular biology.

Design Notes: The site map is a good place to start, as all the pages and sections of this vast site are outlined there. The use of "alt" tags is intermittent throughout the site.

http://www.pbs.org/wgbh/evolution/
(PBS Evolution)

Site Content: PBS hosts this site, which is a companion to its video series *Evolution,* originally broadcast in 2001. Although the site is supplemental to the video series, it is also an excellent standalone resource. There are seven videos ("Darwin's Dangerous Idea"; "Great Transformations"; "Extinction!"; "The Evolutionary Arms Race"; "Why Sex?"; "The Mind's Big Bang"; "What About God?") and seven corresponding sections of the Web site. Each section includes specific hands-on activities, Web activities, teacher resources, and informational text.

Design Notes: QuickTime, RealPlayer, Shockwave, and Flash are all incorporated at various parts of the site. Throughout the site, informative "alt" tags are used consistently for images.

http://www.pbs.org/wgbh/nova/genome/
(Cracking the Code of Life)

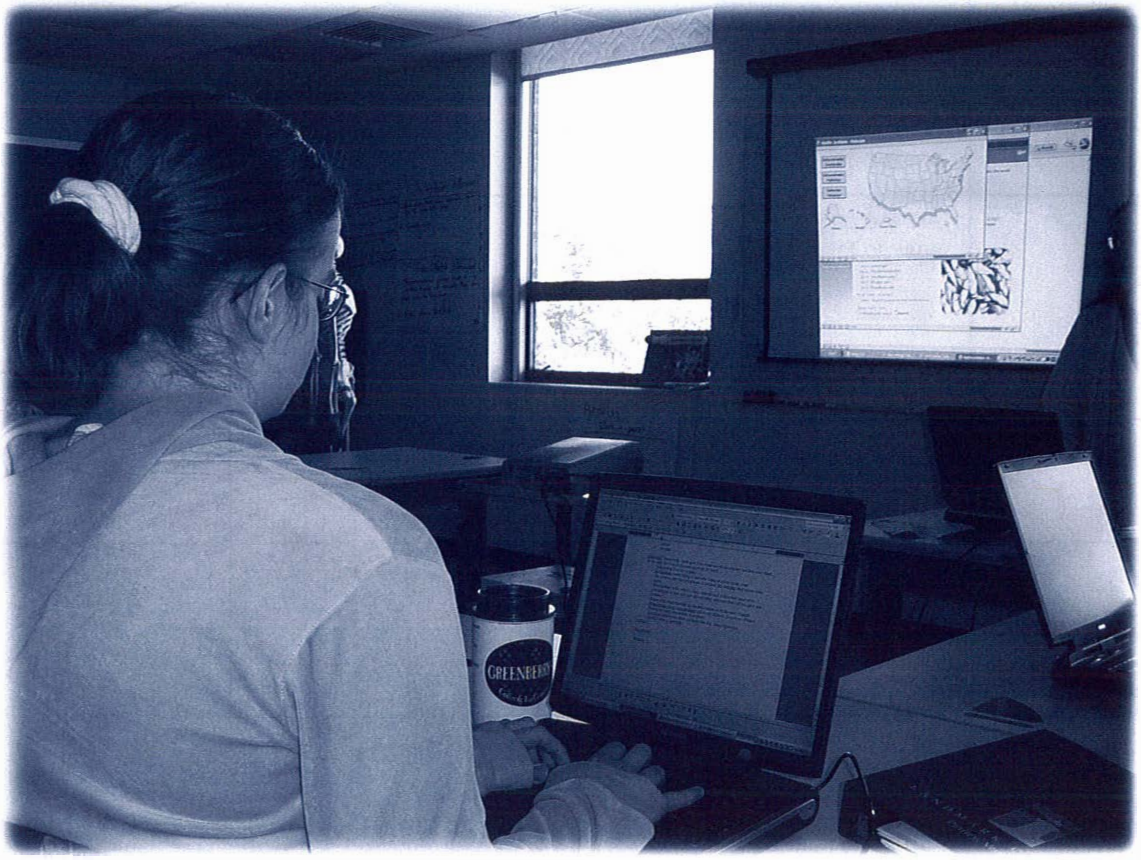
Site Content: This is the companion Web site to the PBS show *Cracking the Code of Life*, originally broadcast in 2001. The comprehensive site contains interviews with genetic scientists, a QuickTime version of the PBS show, information on understanding genetics, interactive animations, and more—all about genetics. Instructor resources for integrating the site in a course are also included.

Design Notes: Any section of this site that employs Shockwave is duplicated in a text-based version. "Alt" tags are included with all images.

CD-ROMs and Diverse Learners

After vetting ten subject-specific CD-ROMs through a process similar to the one we used for the Web site reviews, we do not recommend any for use with students who learn differently. (The CD-ROM evaluation form is included with the Web site evaluation form at the end of this section.) Unlike the recommended Web sites, CD-ROMs generally do not meet many of the basic requirements for use with diverse learners, specifically:

- Since CD-ROMs can hold vast amounts of information, clear navigation is a paramount need. Of the CD-ROMS we reviewed, navigation was often confusing; once the user started down one topic track, it was very difficult to change to another or to go back to the beginning.
- There is little or no flexibility in adjusting text or window size.
- Many CD-ROMs include clickable vocabulary words that, once clicked, jump the user to a new page. However, the user was not always taken directly to the definition for the word clicked, but to the top of the glossary, leaving users to find the word themselves.
- The ability to search the CD-ROM was variable and inconsistent.



WEB SITE EVALUATION FORM

Web site address: ______________________________

Evaluator: ______________________________

General learning disability categories	**Abbreviation**
Reading, decoding, and vision issues	Reading
Considerations when using a screen reader	Screen Reader
Distractibility, short-term memory, and attention issues	Attention
Content comprehension issues	Comprehension

Rating Scale: 1 = Meets learning profile needs poorly; 5 = Meets learning profile needs completely

Learning Profile(s) Addressed	Assessment Question	Rating						Comments
	Subjective questions	1	2	3	4	5	n/a	
Attention	Are the overall design and layout appealing?							
Reading Attention Comprehension	Are the pages grouped in logical, easy-to-follow categories?							
Attention Comprehension	Is the information easy to get to?							
Attention Comprehension	What is the quality of the static graphical images? Do these images enhance the resource or distract from the content?							

Learning Profile(s) Addressed	Assessment Question	Rating						Comments
	Subjective questions	1	2	3	4	5	n/a	
Reading Attention Comprehension	Is the arrangement of links uncluttered, clearly organized, and easy to understand?							
Reading Attention Comprehension	Is the site navigation easy to use?							
Attention	Is response time fast? Do the pages, images, and/or animations load quickly?							
Attention Comprehension	Do animations, video, or audio add value to the site, or are they distracting?							
Reading Attention Comprehension	Is there enough contrast between elements to easily distinguish them from one another?							
Reading Attention Comprehension	Is the proximity of page elements close enough to aid in recognizing relationships?							
Comprehension	Is the site designed in an easy-to-follow, hierarchical fashion?							
Attention Comprehension	Is there extraneous animation?							

Learning Profile(s) Addressed	Assessment Question *Objective questions*	Yes	No	Comments
Attention Comprehension	Are there advertisements on the site leading to commercial sites?			
Attention Comprehension	Is the site available on a consistent basis?			
Attention	Do links on the site lead to dead ends?			
Attention Comprehension	Is the site searchable?			
Attention Comprehension	Does the site require additional software, plug-ins, or hardware to view?			
Attention Reading	Is the text resizable by the viewer?			
Screen Reader	Does the site have a text-based navigation option?			
Screen Reader	Are the links described enough so that a screen reader can identify them?			
Screen Reader	Are there "alt" tags in the code that provide a text option for images?			
Screen Reader	Does the site employ pop-up windows and new browser windows?			

CD-ROM EVALUATION FORM

CD-ROM title & manufacturer: ______________________________

Evaluator: ______________________________

General learning disability categories	**Abbreviation**
Reading, decoding, and vision issues	Reading
Considerations when using a screen reader	Screen Reader
Distractibility, short-term memory, and attention issues	Attention
Content comprehension issues	Comprehension

Rating Scale: 1 = Meets learning profile needs poorly; 5 = Meets learning profile needs completely

Learning Profile(s) Addressed	Assessment Question	Rating						Comments
	Subjective questions	1	2	3	4	5	n/a	
Attention	Is the overall design and layout appealing?							
Reading Attention Comprehension	Are the pages grouped in logical, easy-to-follow categories?							
Attention Comprehension	Is the information easy to get to?							
Attention Comprehension	What is the quality of the static graphical images? Do these images enhance the resource or distract from the content?							

Learning Profile(s) Addressed	Assessment Question *Subjective questions*	Rating						Comments
		1	2	3	4	5	n/a	
Reading Attention Comprehension	Is the CD-ROM navigation easy to use?							
Attention Comprehension	Do animations, video, or audio add value to the CD-ROM, or are they distracting?							
Reading Attention Comprehension	Is there enough contrast between elements to easily distinguish them from one another?							
Attention Comprehension	Is there extraneous animation?							

Learning Profile(s) Addressed	Assessment Question *Objective questions*	Yes	No	Comments
Attention Comprehension	Is the CD-ROM searchable?			
Attention Comprehension	Does the CD-ROM require additional software, plug-ins, or hardware to view?			
Attention Reading	Is the text resizable by the viewer?			
Screen Reader	Does the CD-ROM have a text-based navigation option?			
Screen Reader	Are the links described enough so that a screen reader can identify them?			

Learning Profile(s) Addressed	Assessment Question *Objective questions*	Yes	No	Comments
Screen Reader	Are there “alt” tags in the code that provide a text option for images?			
Screen Reader	Does the CD-ROM employ pop-up windows and new browser windows?			

COMMENTS:

5 INTRODUCTION TO ACTIVITIES

In Sections 6 through 10, we present a sampling of introductory biology classroom activities that fall within the broad curricular categories of teaching scientific inquiry, cell biology, genetics, evolution, and ecology. We chose to create activities in these content areas because they represent the core content of most introductory biology courses.

The nineteen activities in these sections are not meant as a prescribed curriculum to be carried out in some lock-step sequence. Instead, they are intended to show how the educational principles, widely beneficial practices, and instructional techniques presented in Sections 1 through 3 of this book can be applied to specific content-based lessons. Instructors can use them in any order that suits their particular curriculum. The activities are described briefly in the introductions to the five sections following this one.

Each activity includes an *instructor guide* designed to orient instructors to the purpose and scope of the activity as well as to support them in facilitating and assessing student learning. Each instructor guide follows a uniform sequence of sections based on the educational principles and widely beneficial practices. An explanation of the organization and rationale for the instructor guides can be found **on page 181**. Then, **on page 186**, we show explicitly how one of the activities, "Web of Life," applies the educational principles and widely beneficial practices described in detail in Sections 1 and 2.

Some of the activities also include a *student handout* that is intended for easy distribution and use. Most also follow a uniform sequence of sections based on the educational principles and widely beneficial practices. An explanation of the organization and rationale for the student handouts can be found **on page 184**. All student handouts are located in Appendix C and may be photocopied. Each one is sequentially numbered beginning at page 1, thus acting as a complete self-contained unit once it is photocopied and distributed to students. "Tabs" printed down the outer edge of each handout page identify the activity it is related to.

Microsoft Word and rich text format versions of each student handout have also been included on the CD found on the inside front cover of this book.

Instructor Guide to Activities: Organization and Rationale

Name of Activity	→	Each activity has been named to reflect the concept(s) taught.
Time Required	→	It is helpful for an instructor to have a sense of the time necessary to complete an activity. Estimates are based on the collective teaching experiences of the authors. Some activities can be completed within a sixty-minute class period. Other lab-based activities may take parts of several class periods to complete; others can be completed within a typical two- to three-hour block.
Summary	→	A concise summary of the activity is meant to help an instructor see quickly what the activity involves, what content it teaches, and what learning techniques are employed.
Learning Outcomes	→	One key educational principle for teaching students with diverse learning profiles is to explicity identify learning outcomes. Therefore, this section carefully elaborates what students should be able to do as a result of engaging in the activity. The outcomes are broken down into four types: content outcomes, inquiry outcomes, communication outcomes, and lab or computer skill outcomes. Each outcome is directly linked to the assessment suggestions at the end of the lab or activity. Instructors are encouraged to add their own outcomes. It is helpful for students to know the expected learning outcomes prior to beginning a lab or activity.

National Science Education Standards	A code for the relevant National Science Education Standard is given, together with a referral to Appendix B for details.
Materials	All materials necessary to carry out the activity are listed. If applicable, materials per team of students are also listed. Suggested supplier information is sometimes included.
Instructor Preparation	This section serves a number of purposes. Pedagogical considerations specific to each activity are described. Logistical considerations are previewed so instructors can prepare effectively. Preclass material preparations are explained, and, if appropriate, suggested sequencing of the activity within the biology curriculum is also discussed.
Activator/Connector	In Section 2, "Widely Beneficial Practices," activators and connectors are described as techniques that ready students to learn more effectively. They are tools that help students to draw connections to what they already know or have learned. Sample activators and connectors are included with each of the activities to serve as jumping-off points. Instructors are encouraged to design and use their own activators and connectors.
Activity Sequence	This section explicitly lists the suggested sequence of an activity. Instructors should post this list ahead of time and preview it with students after the introduction and activator/connector are completed, as a way to help students visualize the upcoming lesson and their role in the learning.
Procedure	This section outlines a suggested sequence of steps for leading students through the activity. It includes specific logistical tips, references to the rationale behind a particular step, and references to the particular content that will be explored.
Follow-up Discussion Questions	Various follow-up questions that could be discussed with students upon completion of the procedure are suggested here. Answers to some of the questions are provided in italics. The questions or specific tasks follow a generalized sequence: **(1) review questions**—designed to identify and discuss the main ideas of the lesson

(2) **interpretive questions**—designed to apply the learning

(3) **reflective or "metacognitive"* questions** that ask students to evaluate their learning and offer suggestions for changing the activity to improve its effectiveness

Formative Assessment

→ This section identifies the points within the activity where instructors can gather formative assessment information based on the learning outcomes.

Summative Assessment

→ This section lists some summative assessment ideas that can act as follow-ups to the activity.

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* See Section 1, "Six Guiding Educational Principles," **page 9**, for an explanation of *metacognition*.

Student Handouts: Organization and Rationale

Name of Activity	→	Each activity has been named to reflect the concept(s) taught.
Activator/Connector	→	Includes one or more questions designed to help students relate personal experiences to the topic being investigated, and to start them thinking generally about the activity.
Activity Purpose	→	Introduces the main goal, task, or investigative question for the activity.
General Background	→	Introduces or reviews the concepts and terms that students should already know in order to get the most out of the experience.
Learning Outcomes	→	Lists clear outcomes students are expected to achieve during the activity, and upon which they will be assessed after the activity's completion.
Vocabulary	→	Lists new vocabulary associated with the activity so students can easily reference terms during the activity.
Activity Sequence	→	Provides an orientation for students by listing the order of events that will take place to complete the activity.

Materials	→	Lists the necessary materials students will need to complete the activity.
Procedure	→	Includes a series of directions for students to follow in order to carry out the activity. If it is an inquiry-based lab, this section might be divided into one section covering general procedures and another section that prompts students to generate their own hypotheses and experimental designs. Activities with complex procedures have a checkbox next to each step so that students can track their progress in completing the activity.
Data Analysis and Interpretation	→	Gives directions on what data students should record, the type of data analysis they should conduct on the data, and how the data should be presented (e.g., in a table, as a graph, or both). Some activities include a table for students to fill in.
Follow-up Discussion Questions	→	Includes review, interpretive, and reflective questions that will be discussed by the entire class at the end of the activity, or which are to be answered in writing as part of the assessment. Includes room for students to fill in answers to the questions.
Assessment after Lab	→	There is **no** assessment section included in the student handouts in this manual. We leave the details of this task up to the instructor. The instructor version of each activity, however, suggests various tasks that may be assigned to assess student learning. For summative assessment tasks, it is important to explicitly share with students general information such as due date, the portion of the final grade the assessment is worth, whether it should be done individually or can be done in a group, assessment rubrics, etc.

Web of Life*

Time Required: 1½–2 hours

Summary

This activity can be used as an introduction to the concepts surrounding food chains and food webs, and could occur anytime during an ecology unit of study. The activity can also aid student understanding of some of the interrelationships among organisms on earth (the "web of life") by bringing these concepts to a more personal level. In addition, this activity can set the stage for follow-up discussion on energy relationships, such as biomass and trophic levels. The activity is experiential. It may be helpful for students to discuss the process in small groups of three or four; however, they should prepare their food webs individually.

SUMMARY SECTION DEMONSTRATES:

- Subprinciple 1b: Start instruction at students' point of readiness
- Subprinciple 1c: Base instruction on informal dynamic assessment of students' progress and mastery
- Subprinciple 3a: Incorporate and integrate different language domains and processing modes

Learning Outcomes

After completing this activity, students will be able to:

Content

- Construct a food web diagram that correctly links humans to other living organisms
- Define the following terms: *producer, primary consumer, secondary consumer, tertiary consumer, herbivore, omnivore, carnivore, autotroph, heterotroph*
- Apply these terms to a food web diagram

LEARNING OUTCOMES DEMONSTRATE:

- Subprinciple 5a: Identify agendas, learning goals, means, and standards for assessment

National Science Education Standards: Content Standard C:4:2

(see Appendix B)

Materials

- Newsprint (one sheet for each student)
- Markers (five different colors per student)
- Notebook paper

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* This activity was adapted from Biological Science Curriculum Study (BSCS), *Biological Science: An Ecological Approach* (Dubuque, IA: Kendall Hunt Publishing, 1992).

Instructor Preparation

- Assign students to record all the foods and drinks they consumed for dinner (or the equivalent amount of food) the night before the activity
- Gather materials
- Make copies of student handout **(see Appendix C, "Student • Web of Life")**

Activator/Connector

Prompt students with the following question: Where do you fit in the web of life? Discuss responses.

ACTIVATOR/CONNECTOR DEMONSTRATES:

- Subprinciple 1c: Base instruction on informal dynamic assessment of students' progress and mastery
- "Activator"—one of the Widely Beneficial Practices

Activity Sequence

1. Preview the activity, its purpose, background, and learning outcomes

2. Students construct a food web based on a recent dinner

3. Introduce food web terms and add to food webs

4. Follow-up discussion questions

SEQUENCE DEMONSTRATES:

- Subprinciple 3c: Set clear expectations and support students in meeting them
- Subprinciple 5a: Identify agendas, learning goals, means, and standards for assessment

Procedure

THE ENTIRE PROCEDURE SECTION DEMONSTRATES:

- Widely Beneficial Practices "Clear Directions"
- Subprinciple 2a: Teach strategies and procedures explicitly
- Subprinciple 2b: Break tasks and skills into subskills, staged procedures, and other processes

1. Ask students to break down the food they ate for dinner last night into any known components. For example, if the food was pepperoni pizza, the components could be as follows: For the crust, dough in the form of wheat flour, egg, and water; for the topping, tomatoes, milk in the form of cheese, and beef and pork in the pepperoni. This step can be done on notebook paper rather than on the newsprint. (Remind students that there are checkboxes in the procedure section of their handouts to track their progress in completing the lab.)

2. Ask students to identify whether the ingredients came from a plant or an animal. Cue them to mark plant ingredients with a "P" and animal ingredients with an "A."

3. If the food came from an animal, ask students to list several foods that the animal eats. For instance, the beef and pork can be broken down further into the foods that were consumed by the beef or the pig—corn or wheat. Continue this dissection of each food item until a plant is reached.

4. At this point in the lesson, it may be helpful for clarity to have the instructor show a prepared sample food web on newsprint or the on blackboard.

5. Once students have generated a list of foods and identified the origin of each food down the chain to

plants, have them then create a food web on the newsprint:

a. Begin the web at the bottom of the page with a drawing* of any plants that were consumed (wheat, tomatoes, corn).
b. Next, draw the animals that eat those particular plants (chickens, cattle, pigs).
c. Follow the first-level animals by drawing any animals that may eat them.
d. Lastly, on the top of the food web, students should draw a picture of themselves.

PROCEDURE (STEP 5) DEMONSTRATES:

- Subprinciple 4a: Create a strength-based context
- Subprinciple 4b: Incorporate visual-spatial, kinesthetic, and tactile modalities

6. Once the students have completed their webs, introduce the following terms:
    - Producer
    - Autotroph
    - Primary consumer
    - Heterotroph
    - Secondary consumer
    - Tertiary consumer

PROCEDURE (STEP 6) DEMONSTRATES:

- Subprinciple 3a: Incorporate and integrate different language domains and processing modes

7. Have students label their webs with the correct terms, using a black marker.

8. From each producer, draw a colored line to the primary consumer that eats it. Students should choose one color for these lines.

9. From each primary consumer, draw a line of a different color to any secondary consumers that may eat the primary consumer.

10. If any secondary consumers eat a producer, connect them with yet another color.

11. Display the food webs around the room and allow students a few minutes to view them.

Follow-up Discussion Questions

Follow-up discussion should take place with the entire class at once.

Review:

1. Give students the opportunity to summarize their learning up to this point.

FOLLOW-UP DISCUSSION QUESTIONS (REVIEW) DEMONSTRATE:

- "Summarizers"—one of the Widely Beneficial Practices

Interpretive:

The following questions can be used to introduce the terms *herbivore, omnivore, carnivore,* and *decomposer.*

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* The overall effect of the web will have more impact if the components are drawn rather than listed; however, if necessary, the names can be written.

2. Which of the animals eat only plants? (herbivore) *Examples include cows, chickens, etc.*

3. Which of the foods consumed by animals are also foods that you eat? (omnivore) *Examples include grains, fruits, etc.*

4. Are there any animals that eat only other animals? (carnivore) *Examples include some fish species, such as swordfish and tuna.*

5. The webs you made appear to be unidirectional; what happens to the waste produced by the animals, and/or what happens when the animals die? *Organisms called decomposers "eat" or "recycle" the matter and get the energy from the waste and the dead organisms.*

Reflective:

6. Have students discuss the aspect of the activity that most contributed to their understanding: Was it the visuals? the teacher questions? the group discussion? or the hands-on creating?

FOLLOW-UP DISCUSSION QUESTIONS (REFLECTIVE) DEMONSTRATE:

- Subprinciple 6a: Build reflection into the process of learning

Formative Assessment

Students will demonstrate their knowledge of the human role in food webs through their creation of a personal food web graphic. They will show their understanding of key food web terms through their food web graphic, as well as through the discussion that follows the development of the graphic.

FORMATIVE ASSESSMENT DEMONSTRATES:

- Subprinciple 5c: Link assessment to specific learning goals

Summative Assessment

Have students draw a sample food web of a person who is a vegetarian (or interview a vegetarian to gather data for the web on his or her diet). Ask students to label the appropriate trophic levels. Provide additional thought or analysis questions such as the following:

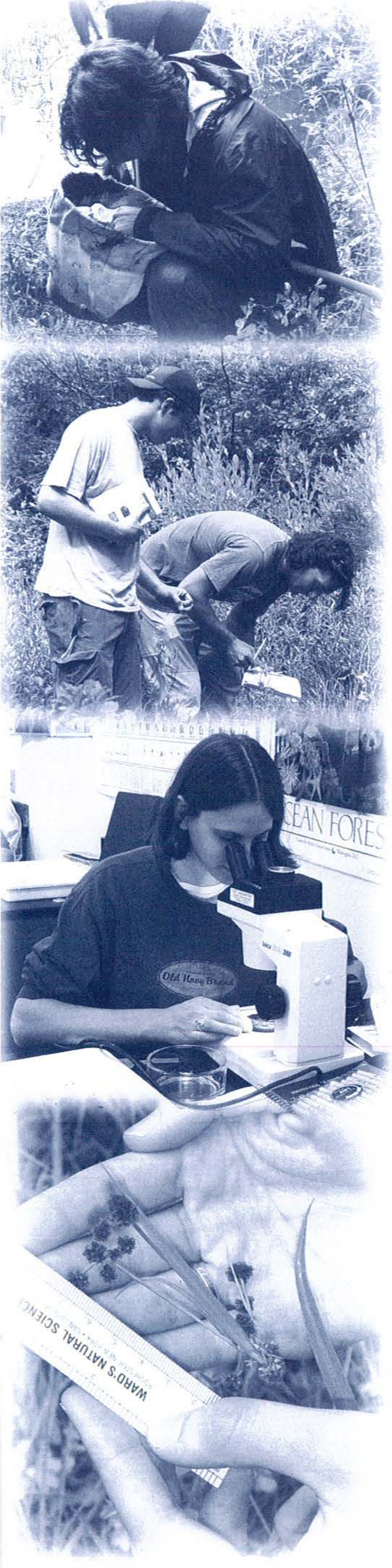
- How many trophic levels exist in a vegetarian food web vs. a meat eater's food web?
- Are humans who are vegetarians still considered omnivores?

SUMMATIVE ASSESSMENT DEMONSTRATES:

- Subprinciple 5c: Link assessment to specific learning goals

Suggestions for Extended Learning

- Have students complete the "Analyzing Food Webs" activity **on page 209**.
- Have students research examples of humans as tertiary consumers. Challenge them to come up with as many animals as they can that are eaten by humans and that are also secondary consumers in their own food webs.



6

ACTIVITIES: SCIENTIFIC INQUIRY

Introduction

This section contains three paper-based activities designed to teach students about engaging in scientific inquiry. It is essential that students master many of the skills and concepts presented in these activities in order to participate in meaningful scientific inquiry. A short description of each activity follows.

Developing Hypotheses (page 193). Students are guided through a series of instructions and prompts that teach them about observations and hypothesis generation. It is designed to prepare students for completing the "Designing Controlled Experiments" activity as a follow-up. This activity includes a student handout in Appendix C, "Student • Developing Hypotheses."

Designing Controlled Experiments (page 195). Students are guided through a series of instructions and prompts that teach them how to design a controlled experiment. It introduces them to essential concepts such as independent variable, dependent variable, and experimental controls. A student handout is provided in Appendix C, "Student • Designing Controlled Experiments."

Graphing Data (page 198). Students are guided through a series of instructions and prompts that teach them about graph design and interpretation. This activity can easily be carried out in smaller chunks throughout a course. A student handout is provided in Appendix C, "Student•Graphing Data."

Developing Hypotheses

Time Required: 45–60 minutes

Summary

This activity employs a three-step process for learning how to develop testable hypotheses. In Part A, students are asked to develop alternative hypotheses to explain observations provided to them. In Part B (potential outdoor activity), students supply their own observations about the natural world for which they develop hypotheses. Finally, in Part C, students share hypotheses and categorize them into those that can and can't be tested via controlled experimentation.

Learning Outcomes

After completing this activity, students will be able to:

Inquiry Skills

- Distinguish between questions that can and can't be addressed scientifically
- Develop alternative testable hypotheses to explain an observation
- Apply key scientific inquiry vocabulary: *scientific method, observation, hypothesis*

National Science Education Standards: Content Standards A:1:1, A:1:5, and A:2 (see Appendix B)

Materials

Student handout (**see Appendix C**, "Student• Developing Hypotheses")

Instructor Preparation

- This activity is best completed as an in-class experience. It may be beneficial to pair up students to work on the activity.
- Since the second set of exercises requires students to make observations, the instructor may want to move students outdoors or to a new environment to facilitate this process.

Activator/Connector

Can all questions be addressed using the scientific method? What types of questions can be and what types can't be?

Activity Sequence

1. Pass out the student handout
2. Preview the activity, its purpose, background, and learning outcomes
3. Complete the procedure and discussion, including discussion questions

Procedure

1. Have students complete Part A exercises. Initiate classroom discussion and encourage students to share their answers with the class. Address examples of hypotheses that were not scientific in nature or were not in correct format.

2. Consider moving to an outdoor environment. Have students complete Part B exercises requiring them to make their own observations and alternative hypotheses.

3. For Part C, ask student groups to share their results, and allow time for class discussion about hypotheses that are testable under controlled conditions.

Follow-up Discussion Questions

Review:

1. What are the main concepts you have learned from this activity?

Student responses will vary.

Interpretive:

2. After sharing your answers with peers, did you find that any of your hypotheses could not be tested scientifically? Were there any that could not be tested under controlled conditions? How did you decide?

Student responses will vary, but the instructor should emphasize that not all hypotheses can be tested under controlled conditions.

Reflective:

3. Do you feel better able to identify and formulate a testable hypothesis?

4. What aspect of this activity most contributed to your learning?

Formative Assessment

- Students will demonstrate their ability to distinguish between questions that can and can't be answered during the follow-up discussion part of the activity.

- Students will demonstrate their ability to develop alternative hypotheses and apply key scientific inquiry vocabulary during completion of the handout, and during informal sharing of student work at the end of the procedure.

Summative Assessment

- Develop a short quiz on the main concepts and terms in this activity.

- Ask students to generate and submit for assessment one additional observation and hypothesis that applies all terms and concepts from this activity.

Suggestions for Extended Learning

- Have students design a controlled experiment to test one of the hypotheses they developed by completing the activity called "Designing Controlled Experiments" **on page 195**.

- Ask students to provide rationales (explanations) for their hypotheses based on their prior knowledge of the topic.

- Ask students to research whether scientists are currently investigating any of the hypotheses they developed.

Designing Controlled Experiments

Time Required: 45–60 minutes

Summary

This activity employs a developmental approach to teaching the application of the scientific method. Students are provided a step-wise procedure for designing a controlled experiment to test a hypothesis. This activity can be used as a stand-alone tool for introducing the scientific method or as a preparatory step for initiating inquiry-based laboratory projects.

Learning Outcomes

After completing this activity, students will be able to:

Inquiry Skills

- Design controlled experiments to test hypotheses
- Apply key scientific inquiry vocabulary (**see list** on student handout)

National Science Education Standards: Content Standards A:1:1, A:1:2, and A:2 (see Appendix B)

Materials

Student handout and student worksheet (**See Appendix C**, "Student • Designing Controlled Experiments")

Instructor Preparation

Develop a student worksheet for the activity or copy the one provided. The worksheet requires students to provide a hypothesis that is suitable for testing under controlled conditions. The instructor has the option of either providing students with a suitable hypothesis or using the "Developing Hypotheses" activity **on page 193** to ensure that all students have selected appropriate hypotheses for the activity. The activator that follows can serve to start a discussion on the nature of controlled experimentation.

Activator/Connector

Not all fields of science arrive at conclusions through the process of controlled experimentation. Ask students whether they can think of some examples of fields that do and fields that do not.

Activity Sequence

1. Pass out the student handouts (instructions and student worksheet in Appendix C, "Student • Designing Controlled Experiments")

2. Preview the activity, its purpose, background, and learning outcomes

3. Complete the procedure and initiate discussion, including discussion questions

Procedure

1. Give students an overview of the scientific method.

2. Either provide students with a suitable hypothesis for the activity (one that can be tested under controlled conditions) or ask them to choose one they generated in the "Developing Hypotheses" activity **on page 193**.

3. Ask students to design an experiment to test their hypothesis. Ask them to consider and decide upon the following aspects as they sequentially work on their experimental design: the particular treatment and levels of treatment to be used, how to measure the effect of the treatment, the experimental control, and other variables to hold constant.

4. *Note:* Students may design experiments for which there is no immediately identifiable experimental control. For example, if a student decides to test the effect of temperature on bread mold growth, the typical experimental control would be to conduct the experiment in the absence of the independent variable, temperature. Class discussion around these "exceptions to the rule" and how to develop alternative controls can provide valuable critical thinking experiences for students.

5. Ask students to make a prediction as to the outcome of their experiment, in both written and graphic form. If, for example, they have predicted that plant growth will increase with increased levels of potassium, what would that predicted growth look like on a graph?

6. Initiate class sharing and discussion. Student groups can present their experimental designs to the class for feedback using posters or write-on transparencies.

7. Complete the follow-up discussion questions.

Follow-up Discussion Questions

Review:

1. In an experiment, distinguish between an independent variable, a dependent variable, and a variable that must be held constant.

The independent variable is the one variable that, when changed or manipulated within an experiment, best helps to answer an experimental question and test a hypothesis. A dependent variable is the one variable monitored and measured during an experiment to see how it changes in response to the independent variable. All other variables in an experiment must be held at constant levels so as not to influence the course of the experiment as the relationship between the independent and the dependent variable is isolated.

Interpretive:

2. In the spaces below, give an example of a scientific hypothesis that can be tested under controlled conditions and one that can't.

Hypothesis that can be tested under controlled conditions: *Sunflowers grow best when in a clay soil.*

Hypothesis that can't be tested under controlled conditions: *The forests of Canada would have different trees had it not been for the last Ice Age.*

3. Sarah designed an experiment to test whether the length of time spent washing hands reduces the frequency of colds. She asked some students to wash their hands for 30 seconds, some for 60 seconds, and a third group for 90 seconds. What is the independent variable for this experiment? the dependent variable? Provide a minimum of two variables that should be held constant. Provide an experimental control for the experiment.

Variable: *Time spent washing hands*
Dependent variable: *Frequency of colds*
Two examples of other variables to hold constant: *Type of soap used, temperature of water used, etc.*
Experimental control: *No-hand-washing group*

4. Design another experiment based on a different hypothesis. Or, using the same hypothesis, develop an alternative experiment to test it.

Student responses will vary according to their choice of hypothesis.

Reflective

5. In the space below, describe the aspect of this activity that most contributed to your understanding of the scientific method. In addition, describe those aspects of the scientific method you found to be most challenging.

Formative Assessment

Students will demonstrate their ability to design controlled experiments and apply key scientific inquiry vocabulary through their completion of the activity handout, their informal presentation of their work to the whole class, and their responses to the follow-up discussion questions.

Summative Assessment

- Develop a short quiz on the main concepts and terms in this activity.

- Ask students to generate and submit for assessment one additional observation, hypothesis, and experimental design that applies all terms and concepts from this activity.

Suggestions for Extended Learning

- Have students actually carry out their experimental designs to test their hypotheses.
- This activity can be readily linked to two other activities provided in this manual:

1. The "Developing Hypotheses" activity guides students in the process of converting observations about the natural world into hypotheses. It also asks students to distinguish between hypotheses that can and can't be tested under controlled conditions. **(See page 193.)**

2. The "Graphing Data" activity begins by asking students to correctly orient independent and dependent variables to the appropriate axis on a graph, and then offers other exercises to further develop their graphing skills. **(See page 198.)**

Graphing Data

Time Required: This activity is intended to be spread out over several class periods.

Summary

This activity is planned to help students who lack basic graphing skills develop enough proficiency to construct simple bar and line graphs. Students will learn how to determine the independent and dependent variables for an experiment, and how to correctly orient them to the axes of a graph. They will receive guidance on deciding whether to construct a bar or a line graph, how to choose the scale for each axis, how to develop descriptive titles for graphs, and how to state observed trends in written form.

Note: It is highly recommended that these graphing activities be slowly integrated into the curriculum. It's important that students master each part before moving on to the next. There is a checklist (Part F) at the end of the student handout that students may find useful for self-assessment of graphs.

Learning Outcomes

After completing this activity, students will be able to:

Inquiry Skills

- Orient the independent and dependent variables to their respective axes
- Choose an appropriate format for a graph (line or bar)
- Choose appropriate scales for the X and Y axes
- Plot data points on a graph
- Write descriptive titles for a graph
- State observed trends in written form

National Science Education Standards: Content Standards A:1:3, A:1:4, and A:1:6 (see Appendix B)

Materials

The following materials are found **in Appendix C**, "Student • Graphing Data":

- Copies of the Graphing Data student handout (one per student)
- Copies of the Graphing Data Worksheets (one set per student)
- Copies of blank uniform graph paper (multiple copies per student)

Instructor Preparation

- The specific exercises included in this activity are very basic in nature. Students may already possess sufficient skills to construct a simple graph of their experimental data. The instructor may want to assign a graphing exercise to assess student proficiency.

- The instructor will need to decide whether to assign the parts of this activity for completion during or outside of class.

- The Graphing Data student handout is divided into six parts, which can be copied and provided to students either individually or all together in one packet, depending on instructor preference.

- In addition to the Graphing Data student handout, separate worksheets for Parts A through E have been provided for students to record their answers.

- The use of a separate worksheet and standardized graph paper will facilitate rapid assessment of student progress in developing basic graphing skills. A sample graph paper form, which can also be reproduced, has been provided in this manual in Appendix C, "Student•Graphing Data 22."

  Alternatively, the instructor can readily construct a similar form using the "table" feature of Microsoft Word. After creating a place for students to write their name and graph title, the instructor can insert a table that is roughly 30 columns by 40 rows. Extra graph paper can then be quickly printed as needed.

Activator/Connector

Ask students if they have heard the expression "A picture is worth a thousand words" and whether, from their perspective, that statement is true. Ask them to identify some of the advantages of depicting information, including scientific data, in graphic form.

Activity Sequence

This activity is divided into six separate parts:

Part A: Identifying the independent and dependent variables
Part B: Graphing the independent and dependent variables
Part C: Choosing between the bar and the line graph
Part D: Choosing scales for the axes
Part E: Writing figure titles and stating trends
Part F: Checking the graph with a checklist

Procedure

1. Preview the activity, its purpose, background, and learning outcomes.

2. Introduce each part (**see** preceding **Activity Sequence**) as a separate activity.

3. Ask students to complete corresponding worksheets. (*Note:* To successfully complete Part D, some students may require individual instruction on how to plot data points once they have developed the scales for both axes of their graph.)

4. Provide frequent opportunities for practice (**see Formative Assessment** that follows) before moving to the next part.

Follow-up Discussion Questions

Review:

1. Using the graph paper provided by your instructor, construct a complete graph for the following two studies.

   a. Tara designed a study to investigate the relationship between tree trunk diameter and canopy height on a nearby forest plot. Here are her findings:

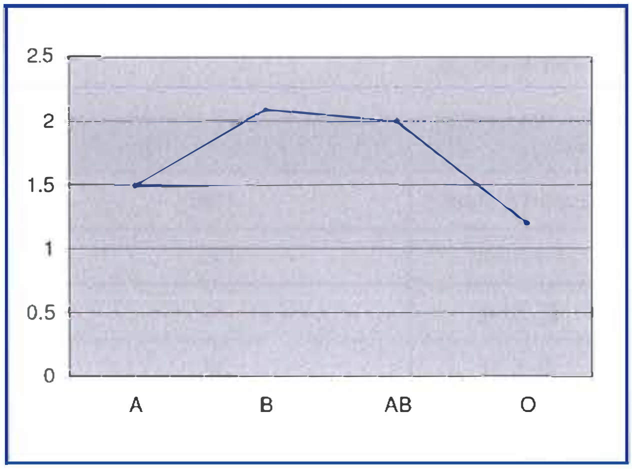
Canopy Height	Average Trunk Diameter in cm
Above 15 meters	158
10–15 m	121
5–10 m	73
0–5 m	32

   b. Drew hypothesized that male peacocks with longer tail feathers would spend more time displaying their tails to females than males with shorter feathers. He exposed five males that differed from each other in the length of their tail feathers to a female, and measured the total amount of time they spent displaying out of a 120-minute period. Here are Drew's data:

Length of Longest Tail Feather in cm	Time Spent Displaying in min
53	23
61	28
59	27
80	67
73	61

Interpretive:

2. Allyson constructed a graph based on the results of her study. She investigated the relationship between blood type and the incidence of flu in humans. For her study, she surveyed five people for each of the four blood types to determine how many incidents of flu they had suffered over the past 24 months. Her graph follows. Has she made any errors in construction? Explain.



There is no descriptive title; neither axis is labeled properly.

3. Correct Allyson's mistakes by constructing a *new* graph of her data, which follow.

Blood Type	Average # Flu Incidents (Over Past 24 Months)
A	1.5
B	2.1
AB	2.0
O	1.2

Reflective:

4. Identify the most difficult aspects of graphing from your perspective. Were you able to develop any strategies that you could share with other students?

5. Do you find it easier to interpret graphs constructed by others now that you understand how graphs are constructed?

Formative Assessment

- All learning outcomes can be assessed either during the in-class completion of this activity through instructor-student discussion, or by collecting student worksheets after the activity is completed.

- Promote the peer evaluation of graphs. Provide each lab group with graph paper, write-on transparencies, write-on markers, and rulers so they can quickly prepare graphs of their results to share with the class.

Summative Assessment

Require students to include graphs in each of their lab reports. Integrate the characteristics of a complete graph into the grading rubric for the report.

Suggestions for Extended Learning

- For any lab activity (whether demonstration or inquiry-based), ask students to predict the outcome of the experiment in graphic form.
- Ask students to bring in examples of graphs from newspapers, magazines, or Web sites that represent examples of how the choice of scale for the axes may distort the data and mislead the viewer.
- Assign graphs at every opportunity to reinforce the skills. Include graphic interpretation as a regular part of your objective assessment instruments for the course.
- Once students have gained mastery over these basic graphing skills, you may want to introduce skills and data sets that are more complex. Teaching students to use Microsoft Excel to create graphs will require additional instruction. The National Science Foundation–sponsored Web site, LabWrite, created at North Carolina State University (http://www.ncsu.edu/labwrite/lwr-home.html), provides a tutorial for students on the fine points of graphing as well as the construction of graphs using Excel. It also provides instruction in the preparation of scientific lab reports.

7 ACTIVITIES: ECOLOGY

Introduction

The six activities that follow fall under the content area of ecology. They are not intended to be used in the particular sequence in which they are presented; rather, instructors are encouraged to use them in any sequence that fits their curriculum. A short description of each activity follows.

Web of Life (page 205). In this activity, students make a food web that includes themselves and is based on their recent food choices. They are introduced to terms relevant to food webs. A complete student handout is provided in Appendix C, "Student•Web of Life."

Analyzing Food Webs (page 209). After viewing a depiction of a forest edge food web, students determine and discuss the trophic roles of each food web member. This activity is a good follow-up to Web of Life. A student handout is provided in Appendix C, "Student• Analyzing Food Webs."

Biogeochemical Cycles (page 212). Using the content of the carbon cycle as the example, students are taught to use a widely applicable writing model to describe a biological process. Besides a writing model template (**page 115**) and a biogeochemical model (**page 216**), no student handouts are provided for this activity.

Fast Plants (page 217). In this long-term lab-based activity, students choose an environmental variable and design an experiment to test its effect on the growth of Wisconsin Fast Plants. Its primary aim is to offer to instructors a model of how to successfully integrate a long-term experiment into a biology course. We have provided a sample long-term project planner and a sample weekly student reporting form at the end of the Instructor Guide for Fast Plants.

Pond Investigation I (page 225). This is a lab-based activity in which students complete a basic pond exploration, including the collection and identification of pond organisms. This activity prepares them for Pond Investigation II. A complete student handout is provided in Appendix C, "Student• Pond Investigation I."

Pond Investigation II (page 229). In this lab-based activity, students choose a sampling technique to test a hypothesis about organism diversity in a pond. It is a guided inquiry–based activity in that the instructor supplies the investigative question and the materials, while the students design their own procedure and draw the subsequent conclusions. A complete student handout is provided in Appendix C, "Student• Pond Investigation II."

Web of Life

Time Required: 1½–2 hours

Summary

This activity can be used as an introduction to the concepts surrounding food chains and food webs, and could occur anytime during an ecology unit of study. The activity can also aid student understanding of some of the interrelationships among organisms on earth (the "web of life") by bringing these concepts to a more personal level. In addition, this activity can set the stage for follow-up discussion on energy relationships, such as biomass and trophic levels. The activity is experiential. It may be helpful for students to discuss the process in small groups of three or four; however, they should prepare their food webs individually.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Construct a food web diagram that correctly links humans to other living organisms
- Define the following terms: *producer, primary consumer, secondary consumer, tertiary consumer, herbivore, omnivore, carnivore, autotroph, heterotroph*
- Apply these terms to a food web diagram

National Science Education Standards: Content Standard C:4:2 (see Appendix B)

Materials

- Newsprint (one sheet for each student)
- Markers (five different colors per student)
- Notebook paper

Instructor Preparation

- Assign students to record all the foods and drinks they consumed for dinner (or the equivalent amount of food) the night before the activity
- Gather materials
- Make copies of student handout (**see Appendix C**, "Student • Web of Life")

Activator/Connector

Prompt students with the following question: Where do you fit in the web of life? Discuss responses.

Activity Sequence

1. Preview the activity, its purpose, background, and learning outcomes

This activity was adapted from Biological Science Curriculum Study (BSCS), *Biological science: An ecological approach* (Dubuque, IA: Kendall Hunt Publishing, 1992).

2. Students construct a food web based on a recent dinner

3. Introduce food web terms and add to food webs

4. Follow-up discussion questions

Procedure

1. Ask students to break down the food they ate for dinner last night into any known components. For example, if the food was pepperoni pizza, the components could be as follows: For the crust, dough in the form of wheat flour, egg, and water; for the topping, tomatoes, milk in the form of cheese, and beef and pork in the pepperoni. This step can be done on notebook paper rather than on the newsprint. (Remind students that there are checkboxes in the Procedure section of their handouts to track their progress in completing the lab.)

2. Ask students to identify whether the ingredients came from a plant or an animal. Cue them to mark plant ingredients with a "P" and animal ingredients with an "A."

3. If the food came from an animal, ask students to list several foods that the animal eats. For instance, the beef and pork can be broken down further into the foods that were consumed by the beef or the pig—corn or wheat. Continue this dissection of each food item until a plant is reached.

4. At this point in the lesson, it may be helpful for clarity to have the instructor show a prepared sample food web on newsprint or the on blackboard.

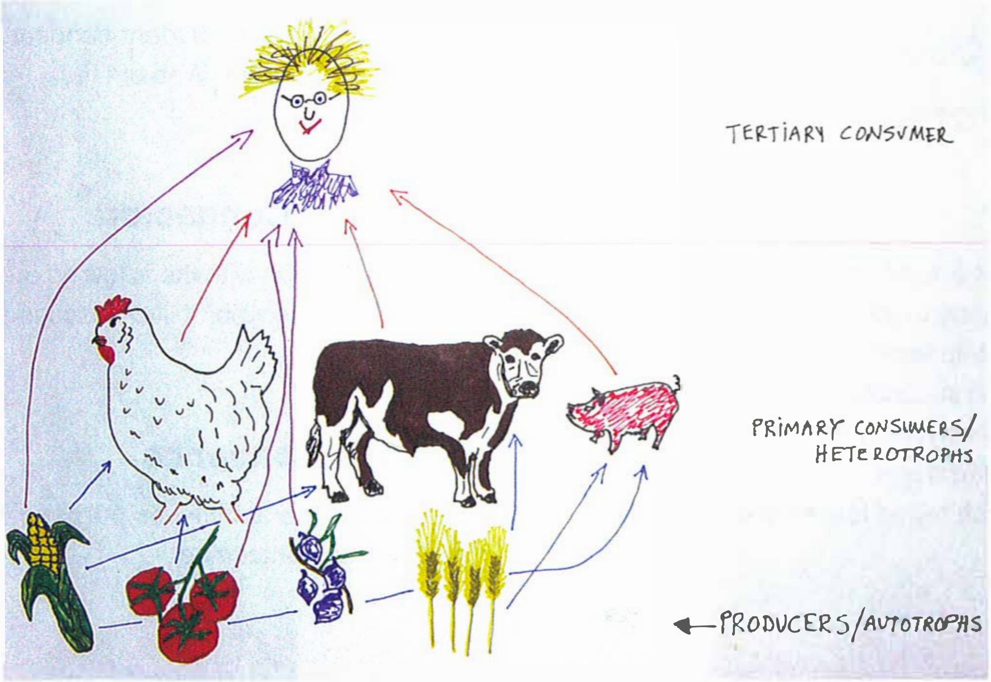


Figure 7.1. Sample food web

5. Once students have generated a list of foods and identified the origin of each food down the chain to plants, have them then create a food web on the newsprint:
   a. Begin the web at the bottom of the page with a drawing* of any plants that were consumed (wheat, tomatoes, corn).
   b. Next, draw the animals that eat those particular plants (chickens, cattle, pigs).
   c. Follow the first-level animals by drawing any animals that may eat them.
   d. Lastly, on the top of the food web, students should draw a picture of themselves.

6. Once the students have completed their webs, introduce the following terms:

- Producer
- Autotroph
- Primary consumer
- Heterotroph
- Secondary consumer
- Tertiary consumer

7. Have students label their webs with the correct terms, using a black marker.

8. From each producer, draw a colored line to the primary consumer that eats it. Students should choose one color for these lines.

9. From each primary consumer, draw a line of a different color to any secondary consumers that may eat the primary consumer.

10. If any secondary consumers eat a producer, connect them with yet another color.

11. Display the food webs around the room and allow students a few minutes to view them.

Follow-up Discussion Questions

Follow-up discussion should take place with the entire class at once.

Review:

1. Give students the opportunity to summarize their learning up to this point.

Interpretive:

The following questions can be used to introduce the terms *herbivore, omnivore, carnivore,* and *decomposer.*

2. Which of the animals eat only plants? (herbivore)

   Examples include cows, chickens, etc.

3. Which of the foods consumed by animals are also foods that you eat? (omnivore)

   Examples include grains, fruits, etc.

4. Are there any animals that eat only other animals? (carnivore)

   Examples include some fish species, such as swordfish and tuna.

5. The webs you made appear to be unidirectional; what happens to the waste produced by the animals, and/or what happens when the animals die?

   Organisms called decomposers "eat" or "recycle" the matter and get the energy from the waste and the dead organisms.

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*The overall effect of the web will have more impact if the components are drawn rather than listed; however, if necessary, the names can be written.

Reflective:

6. Have students discuss the aspect of the activity that most contributed to their understanding: Was it the visuals? the teacher questions? the group discussion? or the hands-on creating?

Formative Assessment

Students will demonstrate their knowledge of the human role in food webs through their creation of a personal food web graphic. They will show their understanding of key food web terms through their food web graphic, as well as through the discussion that follows the development of the graphic.

Summative Assessment

Have students draw a sample food web of a person who is a vegetarian (or interview a vegetarian to gather data for the web on his or her diet). Ask students to label the appropriate trophic levels. Provide additional thought or analysis questions such as the following:

- How many trophic levels exist in a vegetarian food web vs. a meat eater's food web?
- Are humans who are vegetarians still considered omnivores?

Suggestions for Extended Learning

- Have students complete the "Analyzing Food Webs" activity **on page 209**

- Have students research examples of humans as tertiary consumers. Challenge them to come up with as many animals as they can that are eaten by humans and that are also secondary consumers in their own food webs.

Analyzing Food Webs

Time Required: 25 minutes

Summary

This activity applies students' understanding of trophic-level food web relationships by having them analyze diagrammatic depictions of food webs. The activity could be completed in class or outside of class.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Define the following terms as they relate to trophic levels: *producer, primary consumer, secondary consumer, tertiary consumer, detritivore, omnivore*
- Apply these terms by accurately describing a food web diagram
- Recognize that organisms can occupy more than one trophic level
- Determine the trophic level of organisms by analyzing a food web diagram

National Science Education Standards: Content Standard C:4:2 (see Appendix B)

Materials

- Student handout that includes a worksheet with analysis questions and a model of a forest edge food web (**see Appendix C**, "Student • Analyzing Food Webs")
- Colored markers (optional)

Instructor Preparation

- Decide whether students will carry out this activity in teams or as individuals.
- Copy the student handout ahead of time.
- The activity would fit best after food webs and energy flow have already been introduced in some fashion.

Activator/Connector

Have students quickly draw some depiction of a "web" in their notes. Then ask why ecologists may have chosen the term "food web" to show feeding relationships.

Activity Sequence

1. Preview the activity, its purpose, and learning outcomes

2. Students work individually or in pairs to analyze the Model Food Web using the analysis questions on the Analyzing Food Webs Worksheet to guide them

3. Compare answers and discuss

Procedure

1. Pass out the student handout that includes the food web model and analysis questions.

2. Give students the option of working individually or in a team of two.

3. Explain that the task is to use the food web model to answer the analysis questions.

4. Give the students approximately 10 minutes to analyze the food web model.

5. Options:
   a. Distribute to students colored markers or highlighters so they can color code the trophic levels on the food webs as they work through the activity.
   b. Distribute to students a list of all organisms in the food web to use as a note-taking guide as they work through the task of identifying which organism is in each trophic level.

Follow-up Discussion Questions

Review and Interpretive:

1. When all students have finished the questions on their own or in their teams, lead a class discussion that shares student answers to the analysis questions.* Let students resolve differences of interpretation by asking them to justify their answers.

How many producer species? List.

Four—Goldenrod; Grass; Oak Acorn; Blackberry

How many primary consumers? List.

Four—Mouse; Rabbit; Deer; Squirrel

How many secondary consumers? List.

Four—Mink; Snake; Hawk; Coyote

How many tertiary consumers? List.

One—Hawk

List the members of the longest food chain.

Grass ⟶ Mice ⟶ Snake ⟶ Hawk

Do any organisms belong to two trophic levels? Which ones and why?

Coyote, because it eats both producers and primary consumers; and hawk, because it eats both primary consumers and secondary consumers.

What essential food web role has been left out of the web?

Detritivores or decomposers

Which species is at the highest possible trophic level in this web? Why?

The hawk, because it is at the end of the longest food chain in the web.

2. Ask students to summarize their key learning from this activity.

Reflective:

3. Ask students if this activity played to their learning strengths or weaknesses.

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*If appropriate for the group, use the discussion technique called "random group check." **See page 110** for further elaboration on this technique.

Formative Assessment

Students will demonstrate their knowledge of trophic levels and accurate use of trophic-level terminology orally when completing the food web analysis in their small groups, as well as in the discussion period that follows.

Summative Assessment

- Assign an additional food web model for students to analyze for further practice, using the same or similar analysis questions. Collect and assess accuracy of students' work based on the learning outcomes.
- Include a similar analysis task as part of a quiz or test on ecology.
- Assign to students the task of building a 3-D food web model that includes all the key food web terminology.

Biogeochemical Cycles

Time Required: 60 minutes

Summary

Nutrient or *biogeochemical cycles* are key concepts for understanding the interactions between organisms and the environment. Students of biology often encounter difficulty in differentiating the main ideas and ecological relevance of these cycles from their intricate details. This activity sequence is designed to introduce students to the big picture before they are presented with a model for examining the details. It also includes introducing students to a template for writing about biological processes.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Define the term *biogeochemical cycle*
- Give examples of how both the water and the carbon cycle include biotic and abiotic (geological and chemical) components of the biosphere
- Describe the importance of carbon to plants and animals

Communication Skills

- Write a well-organized and coherent summary of a biological process

National Science Education Standards: Content Standard C:4:1, C:5:6, and D:2:1 (see Appendix B)

Materials

- Depictions of both the water and the carbon cycles from texts, overhead transparencies, CD-ROMs, the World Wide Web, etc., preferably in color
- A diagram that depicts a general biogeochemical cycle. **See page 216**
- Student handouts of a writing model for summarizing biological processes (two copies for each student). **See page 115**
- Overhead projector or digital projector/computer (optional)

Instructor Preparation

- This activity requires that students have an understanding of the *abiotic* and *biotic* components of an ecosystem.
- Choose ahead of time which graphic depictions of the water and carbon cycles to use.
- Copy all student handouts.

Activator/Connector

Most students have a basic understanding of the water cycle from their backgrounds, so use the following question to get them to recognize and explain their conceptions of this basic biogeochemical cycle: How does water move from living to nonliving components of the earth? Discuss their conceptions briefly and categorize this phenomenon as an example of a biogeochemical cycle.

Activity Sequence

1. Preview the activity and its learning outcomes

2. Procedure, Part A: Instructor introduction to biogeochemical cycles

3. Procedure, Part B: Instructor-led explanation of the water cycle, with student input

4. Procedure, Part C: Instructor-led demonstration of how to use the writing model to describe the events in the water cycle, with student input

5. Procedure, Part D: Instructor-led explanation of the carbon cycle

6. Follow-up discussion questions

7. Assignment: Students write a summary of the carbon cycle using the writing model

Procedure

Part A: Instructor Introduction to Biogeochemical Cycles

1. Pass out the General Model of a Biogeochemical Cycle to students. Have students look at it on their own briefly. Then provide this prompt:

From this diagram, what can you tell about biogeochemical cycles?

Continue prompting until the basics are uncovered:

- they involve living and nonliving components
- something is moving or cycling between living and nonliving things
- they occur only within the biosphere

2. Break down the word *biogeochemical* into its component parts—“bio”–“geo”–“chemical”—and use this analysis to define the concept. A biogeochemical cycle is the movement of particular essential substances through the biosphere, alternating between biological (biotic), geological (abiotic), and chemical (abiotic) forms.

3. List for students some examples of biogeochemical cycles: water, phosphorus, carbon, and nitrogen. These substances are essential for proper functioning and balance in ecological systems and in individual organisms.

Part B: Instructor-Led Explanation of the Water Cycle

1. Show a version of the water cycle, or construct one with input from the students.

2. Lead a discussion about the water cycle. Students should take notes. Highlight the following:

  a. The importance of the cycle: Water is essential for all organisms because of its unique characteristics.
  b. General features of the cycle: The water cycle carries water through the atmosphere, living systems, and nonliving systems on land and soil.
  c. Specific components of the cycle: Examine one “loop” of the cycle in more detail. Minimally, this should include condensation, precipitation, and transpiration.

3. When finished with the instructor-led explanation, ask students to review the cycle orally in pairs or teams.

Part C. Instructor-Led Demonstration of How to Use the Writing Model to Describe the Water Cycle

1. Using an overhead projection device, display the blank template for the Writing Model for a Biological Process. Distribute two copies on paper to each student. Introduce the model as a tool to organize certain kinds of scientific writing. Using the water cycle information just presented, fill in the writing model with input from students.

2. Assign students to convert the filled-in writing model to paragraph form. This could be assigned to groups of two.

Part D. Instructor-Led Explanation of the Carbon Cycle

Use a clear visual depiction of the carbon cycle to highlight its purpose, general features, and specific components. Distribute the depiction to students. Students should take notes in some form.

Follow-up Discussion Questions

Review:

1. Provide an opportunity for students to summarize their learning about biogeochemical cycles, perhaps in small groups.

2. What do all biogeochemical cycles have in common?

They cycle matter/nutrients through ecosystems and the biosphere. They are all closed loops; no matter/nutrients escape the biosphere. The matter/nutrients go back and forth between biotic and abiotic parts of the ecosystem and biosphere.

3. What are two abiotic phases and two biotic phases within the carbon cycle?

Abiotic phases: carbon dioxide in atmosphere; fossil fuels; marine sediments; etc. Biotic phases: plants; animals; bacteria; etc.

4. How is the carbon cycle essential to plants and animals?

Carbon is involved in the formation of essential organic compounds, such as carbohydrates and DNA. Plants must get carbon from the biosphere through photosynthesis. Animals must get carbon through eating plants or other organisms.

Interpretive:

5. What would happen within the carbon cycle if there were a notable increase in the burning of fossil fuels?

This is a topic of considerable interest and debate among scientists. Obviously, more carbon dioxide would be released into the atmosphere. Some of this extra carbon dioxide would create significant greenhouse warming in the atmosphere. Some might be absorbed in significant amounts by various producers in ecosystems. The idea is that the overall rate of carbon cycling within the earth's system might change, perhaps with some negative ramifications for humans.

Reflective:

6. Was the Writing Model for a Biological Process a useful tool for organizing information?

7. Which aspect of this activity was most congruent with your learning style? least congruent with your learning style?

Formative Assessment

- Students will demonstrate their knowledge of biogeochemical cycles orally during the discussion section of the activity.

- Students will begin to demonstrate their ability to write a summary of a biological process when they produce a draft summary of the water cycle.

Summative Assessment

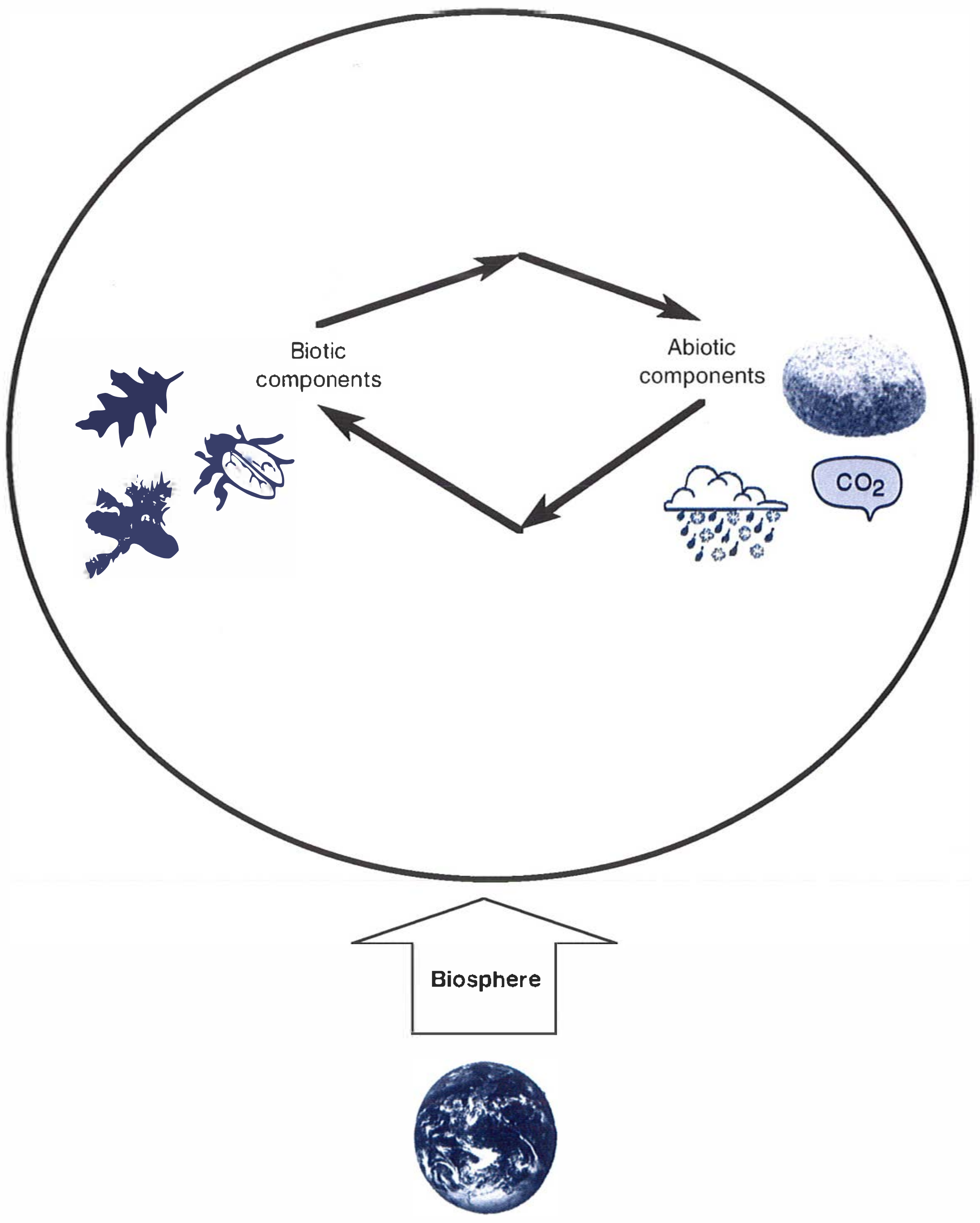
Assign students the task of using the Writing Model for a Biological Process to describe the carbon cycle in writing. The cycle must start and end at the same point and include a minimum of four steps. The product should be in paragraph form. It is highly recommended that the instructor develop a rubric for this writing activity (**see page 127** on Rubrics). The rubric could be given to students as a guide for completing this assignment.

Suggestions for Extended Learning

1. Assign students to apply the Writing Model for a Biological Process template to another cycle (such as the nitrogen or the phosphorus cycle).

2. Assign students to construct three-dimensional models of any biogeochemical cycle discussed in the class.

General Model of a Biogeochemical Cycle



Fast Plants

Time Required: Part of class on various days over a 40-day period. (Specific activities require different amounts of time ranging from 15 minutes to a full lab period.)

Summary

Students will conduct a long-term experiment testing the effects of environmental variables on growth and seed production of Wisconsin Fast Plants. This experiment could occur at any time during an ecology unit of study, but would be most effective after the concept of abiotic variables has been discussed.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Describe the major stages of plant development
- Describe how certain environmental factors affect plant growth

Inquiry Skills

- Collect relevant scientific background on research topics from reliable sources
- Design an experiment to test a hypothesis
- Independently collect and record data over an extended period
- Display data in both tabular and graphic forms
- Calculate averages
- Decide whether data support hypotheses

Communication Skills

- Provide oral weekly progress reports to class
- Write a scientific lab report that accurately summarizes the experiment

National Science Education Standards: Content Standards A:1:1, A:1:2, A:1:3, A:1:4, A:1:5, A:1:6, and A:2 (see Appendix B)

Materials

- All materials for growing Wisconsin Fast Plants are available from most biological supply companies. These include
  - — seed,
  - — containers, growth media, and fertilizer, and
  - — supplemental lighting

- Additional materials will be necessary for individual group experiments (e.g., chemicals, etc.)

- Lab notebook/journal

Instructor Preparation

- Make copies of the Worksheet for Designing Controlled Experiments in Appendix C, "Student•Designing Controlled Experiments 9" to aid students in designing their long-term fast plants project.

- Order growth media and other materials that students may want to use in their experiments (e.g., acids and bases to test effects of pH, black cloth to test effects of light, etc.). Additional materials may be required if students design unique experiments that the instructor has not prepared for.

- Prepare a long-term project planner for students (see sample **on page 222**) that contains the following:
  — A section for student groups to exchange names and contact information (to aid in team communication)
  — A calendar that indicates the important dates when various aspects of the project will occur (to aid students in time management)
  — Any other pertinent information

- Optional: Create a report form for students to submit periodically, containing written updates of their experiments. This would be an organizational tool for students, and would allow instructors to more carefully assess and document the progress of the experiment.

- Set up equipment.

Activator/Connector

Have you ever conducted a long-term project? What are some benefits of doing a long-term vs. a short-term project? some challenges?

Have you ever watched a plant grow? What are the growth stages of a plant? Based on your experience, how do levels of water or heat affect the growth rate of plants? How can growth rate be measured? What are some interesting and/or important questions that could be asked about factors that affect plant growth?

Activity Sequence

1. Pass out student lab handouts

2. Preview activity, purpose, and learning outcomes using long-term project planner

3. Procedure

4. Follow-up discussion questions

5. Assessment

Procedure

1. Assign students to groups of two to four and have them fill out the team member portion of their long-term project planner.

2. Present background information necessary for conducting the project, including information on Wisconsin Fast Plants and their normal growth requirements. There is a lot of supportive material available through Carolina Biological (manuals, videos, teacher guides, etc.).

3. Instruct students in how to properly design an experiment (see "Developing Hypotheses," **page 193**, and "Designing Controlled Experiments," **page 195**). Guide each student group in the following:
   a. Formulating a clear question
   b. Developing a hypothesis to test
   c. Brainstorming independent environmental variables that might be tested to determine their effects on plant growth (e.g., amount of water or fertilizer, temperature, quantity and quality [color] of light, pH, presence of a pollutant such as a heavy metal or bleach)
   d. Brainstorming dependent variables that best

measure plant growth (e.g., plant height, days to flowering, number of seeds produced)

e. Developing a procedure, including appropriate levels of the independent variable, an experimental control, and other variables that should be held constant. (*Note:* To minimize effects of genetic and environmental variability on results, it is recommended that each treatment level consist of a minimum of 12 plants.) Some groups may be able to develop their procedures independently, while others may need different degrees of teacher input. Some data may need to be collected only once every three days (e.g., plant height), while other data (e.g., flowering date) may need to be assessed daily.

f. Predicting the outcome of the experiment

4. Each procedure should be reviewed by the instructor and possibly a peer group. Alternatively, each research group could be asked to prepare a brief overview of its research proposal, including relevant background information, hypothesis, experimental design, and prediction. Allow other groups the opportunity to provide feedback and make suggestions for improvement.

5. Instruct students in any lab skills that might be needed for their particular procedure, such as using a balance (including taring), making solutions, making a table to record data (**see Figure 7.2**), and keeping an organized lab journal in which to record data.

6. Have each group set up its experiment and begin to carry out its experimental procedure.

7. Sometime during the several weeks that data is being collected by students, instruct them in how to analyze the results (e.g., take the average height for each treatment group for each day of the experiment) and make graphical representations of the data. If students require instruction in graph construction and interpretation, consider using the "Graphing Data" activity **on page 198** to teach these skills.

8. As data is collected, each group should interpret results and orally present them to the class to allow for comparisons. It is recommended that this be done weekly, and also at the end of the project. See the sample of a Fast Plants weekly student report form **on page 224**.

Follow-up Discussion Questions

Ask students the following questions:

Review:

1. Based on the class's data, what environmental conditions are best and worst for growing Wisconsin Fast Plants?

Interpretive:

2. How might the results of this lab be used to advise farmers on how to grow their crops, or advise politicians on environmental policy?

Reflective:

3. How could each group have improved upon the organization or procedure of the long-term project?

4. What are sources of error in the lab?

5. What aspect of the activity most contributed to students' understanding? Was it the small-group interaction or the larger class discussions? Was it the hands-on manipulation?

6. Which part of the lab was most challenging?

Level of Independent Variable	Plant	Height (cm) on Day ___ (Dependent Variable)													
		1	4	7	10	13	16	19	22	25	28	31	34	37	40
1	1														
	2														
	3														
	4														
	5														
	6														
	7														
	8														
	9														
	10														
	11														
	12														
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	3														
	4														
	5														
	6														
	7														
	8														
	9														
	10														
	11														
	12														

Figure 7.2. Sample data table

Formative Assessment

All interactions with students as they design and carry out their experiments can provide assessment information for each learning outcome. Most important, the weekly oral reports are key for collecting assessment data on the content learning outcomes as well as on inquiry skills learning outcomes such as displaying data, calculating averages, and deciding whether data support hypotheses.

Summative Assessment

The following are suggestions for assessment after the lab work is completed:

- Ask students to write a lab report using the Lab Report Template **on page 163**.
- Alternatively, ask students to develop a research poster and communicate findings during a poster session. See "Poster Presentations" **on page 151**.

Suggestions for Extended Learning

Have students use their experimental results to refine their initial hypothesis and create a new experimental design that could yield additional data on their chosen topic.

FAST PLANTS
SAMPLE LONG-TERM PROJECT PLANNER

Name: ______________________________

Team members' names and contact information:

Members' Names	*Phone*	*E-mail Address*
______________	______________	______________
______________	______________	______________
______________	______________	______________

Sample Project Timeline — Dates to look forward to!

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
Day 1 Date: Project described Teams determined	*Day 2 Date:* Developing Hypotheses & Designing Experiments activity (Part 1)	*Day 3 Date:* Developing Hypotheses & Designing Experiments activity (Part 2)	*Day 4 Date:* Brainstorm variables & possible hypotheses. Develop experimental design—peer evaluate	*Day 5 Date:* **Experimental Design Due!** Meet with instructor for review
Day 6 Date: Set up experiment, with lessons on specific skills as necessary	*Day 7 Date:* Discuss record-keeping skills	*Day 8 Date:* Review/teach graphing skills	*Day 9 Date:* Collect data Graph Prepare weekly report	*Day 10 Date:* ☆ **Present weekly report of your experiment to the class**
Day 11 Date: Team meeting with teacher for updates Collect data	*Day 12 Date:* Ongoing experimentation →	*Day 13 Date:*	*Day 14 Date:* Collect data Graph Prepare weekly report	*Day 15 Date:* ☆ **Present weekly report of your experiment to the class**
Day 16 Date: Team meeting with teacher for updates Collect data	*Day 17 Date:* Review the skills of developing hypotheses & designing experiments	*Day 18 Date:* ☆ **Quiz on developing hypotheses & designing experiments**	*Day 19 Date:* Collect data Graph Prepare weekly report	*Day 20 Date:* ☆ **Present weekly report of your experiment to the class**

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
Day 21 Date: Team meeting with teacher for updates Collect data	*Day 22 Date:* Review the skills for graphing	*Day 23 Date:* ☆ **Quiz on graphing**	*Day 24 Date:* Ongoing experimentation	*Day 25 Date:* ☆ **Present weekly report of your experiment to the class (optional)**
Day 26 Date: Team meeting with teacher for updates	*Day 27 Date:* Ongoing experimentation →	*Day 28 Date:* →	*Day 29 Date:* →	*Day 30 Date:* ☆ **Present weekly report of your experiment to the class (optional)**
Day 31 Date: Team meeting with teacher for updates	*Day 32 Date:* Ongoing experimentation →	*Day 33 Date:* →	*Day 34 Date:* Collect seed data Graph Prepare weekly report	*Day 35 Date:* ☆ **Final weekly report of your experiment to the class—students compare results**
Day 36 Date: Teacher presents poster session project description & rubric	*Day 37 Date:* Organize information and materials for poster →	*Day 38 Date:* →	*Day 39 Date:* Students present posters to each other—peer evaluate	*Day 40 Date:* ☆ **Poster Session for public display**

FAST PLANTS
SAMPLE WEEKLY STUDENT REPORT

Directions: The following form provides you with an outline for your weekly updates to the class.

Team Members' Names:

Week # _____

1. Review with the class the investigative question and hypothesis that your group's experiment is based on.

2. Present and describe an updated graph of your data.

3. Report anything new that you may have observed; for example, if flowering has begun.

4. Share any questions or problems that have arisen in the past week.

Pond Investigation I

Time Required: 3–3½ hours (spread over two class meetings, and depending on transportation distances)

Summary

This activity introduces students to proper field skills required for an examination of macroinvertebrates that dwell in a pond. The investigation could occur at any time during an ecology unit of study. It is meant to serve as a discovery lab that sets the stage for an inquiry-based problem to be addressed in "Pond Investigation II" (**see page 229**).

Learning Outcomes

After completing this activity, students will be able to:

Content

- Identify a variety of different macroinvertebrates inhabiting a local pond

Inquiry Skills

- Determine the relative abundance of the various macroinvertebrates inhabiting the pond
- Develop alternative hypotheses that explain why certain inhabitants are less abundant than others

Lab Skills

- Collect aquatic invertebrates using nets and other collecting tools
- Use a dissecting microscope
- Use identification guides

National Science Education Standards: Content Standard A:2 and C:4:3 (see Appendix B)

Materials

Field

- Collecting nets—several (Ward's D-Frame Aquatic Net #10 W 0620 recommended)
- Buckets for holding organisms and pond water
- Enamel or plastic pans for sorting and viewing aquatic invertebrates
- Meter sticks—several
- Hip waders—a pair per sampling team
- Rubber boots—for use by nonsampling students
- Tweezers for moving organisms within the containers
- Plastic pipettes or eyedroppers for moving organisms
- Clipboards

Materials

In Lab

- Dissecting microscopes
- Tweezers
- Probes
- Plastic petri dishes for holding organisms

- Identification guides (**see bibliography** at end of this Instructor Guide for suggestions)
- Plastic pipettes/eyedroppers
- Drawing materials

Instructor Preparation

Before the lab, the instructor will have to identify a nearby pond that is accessible. A landowner may need to be contacted for permission to use the pond. The main accessibility concerns include proximity to campus or school, parking of vehicles, a pond shoreline that accommodates the group size, and varying water depths to accommodate the experimental design if "Pond Investigation II" will be used as a follow-up.

As this lab requires that students identify macroinvertebrate pond organisms using identification guides, it is recommended that instructors decide ahead of time which taxonomic level of identification would be most appropriate for their students. In general, it is recommended that introductory biology students identify to the taxonomic level of order. However, some advanced groups may be capable of identifying to the taxonomic level of family.

Activator/Connector

- Ask students to brainstorm what kinds of animals they might expect to find in the pond.
- Ask students to describe insect life cycles; at this time, a review of complete and incomplete metamorphosis may be appropriate.

Activity Sequence

1. Preview with students the lab's purpose, background, and learning outcomes

2. Gather equipment and travel to pond

3. Learn how to use equipment and gather specimens from pond

4. Return to lab and use microscopes and field guides to identify organisms collected

5. Follow-up discussion questions

Procedure

Part A (in the field)

Remind students that there are checkboxes in the Procedure sections of their handouts to track their progress in completing the lab.

1. Collect all relevant field equipment and materials and take students to the pond under study.

2. Have students observe the pond and the surrounding area. Discuss their observations.

3. Instruct students on the proper equipment handling technique as well as proper use of the collecting tools. A review of general field lab etiquette and/or rules may be appropriate as well.

4. Have students collect samples as instructed.

5. Have students observe and record the relative abundance of each type of organism. A general observation is all that is necessary; an accurate count is not required.

6. Have students choose a representative sample of each type of organism to place in buckets (with water) to take back to the lab.

Part B (in the lab)

1. Introduce students to identification resources. Using microscopes and identification books, students should identify as many organisms as possible.

2. Have students create a master list of organisms identified for the entire class.

3. Have students sketch at least three of the organisms that they observed, using the sheets provided at the end of their handout.

Follow-up Discussion Questions

These questions are intended to get students to think ecologically about what they have discovered, and perhaps make some trophic-level connections.

Review:

1. How many different species were identified?

   Student responses will vary from class to class.

2. What species were the most abundant?

   Student responses will vary, but ideally will show that species numbers at the lower trophic levels are more abundant.

3. What organisms had low numbers?

   Student responses will vary, but ideally will show that species numbers at the higher trophic levels are less abundant.

4. What did you learn about macroinvertebrates that you did not know before?

   Student responses will vary.

Interpretive:

5. Give two possible hypotheses as to why the pond would have so many of the most abundant species.

   Some possible hypotheses include trophic level/biomass principles; ease of collection; recent hatching of some species; etc.

6. Give some hypotheses as to why the numbers of other organisms were low.

   Some possible hypotheses include trophic level/biomass principles; difficulty with collection; rare or endangered for some reason.

Reflective:

7. What more would you like to know about macroinvertebrates?

8. What did you like and dislike about this lab?

9. What aspect of this lab was most difficult for you and why?

10. What did it teach you about how you learn best?

Formative Assessment

- Students will demonstrate their use of proper field techniques during the field trip component of the lab.

- Students will show their skills with identifying aquatic macroinvertebrates in the microscope component of this lab.

- Students will show their understanding of the diversity of organisms found in a local pond and their relative abundance through oral participation in the discussion that follows the lab.

- Students will also demonstrate their ability to develop hypotheses about the abundance of pond life during the discussion that follows the lab.

Summative Assessment

- Assign students to make a "field guide" for all or some of the pond organisms found during the investigation. The field guide would include name, key identifying features, and a sketch of each organism.

- Assign students to complete some form of comprehensive lab report that documents their achievement of the learning outcomes.

Suggestions for Extended Learning

- Assign each student an organism that was found in the pond. They must use the Internet or some other reference to figure out what their organism eats and/or other pertinent information about it.

- Using all organisms discovered in the pond, students can be assigned to construct a pond food web.

- Continue to study this pond ecosystem by undertaking the inquiry-based Pond Investigation II **on page 229**.

Suggested Identification Books and Web Resources

Chu, H. *How to Know the Immature Insects.* Dubuque, IA: Wm. C. Brown Company Publishers, 1949.

Lehmkuhl, D. *How to Know the Aquatic Insects.* Dubuque, IA: Wm. C. Brown Company Publishers, 1979.

McCafferty, P. *Aquatic Entomology: The Fisherman's and Ecologists' Illustrated Guide to Insects and Their Relatives.* Sudbury, MA: Jones and Bartlett Publishers, 1981.

Needham, J. *A Guide to the Study of Fresh-Water Biology*: San Francisco: Holden-Day, 1962.

Peckarsky, B., P. Fraissinet, M. Penton, and D. Conklin Jr. *Freshwater Macroinvertebrates of Northeastern North America.* Ithaca, NY: Comstock Publishing Associates, 1990.

Reid, G. *Pond Life.* Golden Guide series. New York: St. Martin's Press, 2001.

Voshell, R. *A Guide to Common Freshwater Invertebrates of North America.* Blacksburg, VA: McDonald & Woodward Publishing Company, 2002.

http://www.microscopy-uk.org.uk/pond/. Online information and identification resource for pond organisms, with great photos.

Pond Investigation II

Time Required: 3–5 hours (depending on transportation and level of student support required)

Summary

This investigation is the inquiry-based follow-up to the exploratory Pond Investigation I (**see page 225**). In this activity, the instructor provides students with an investigative question concerning pond depth and aquatic invertebrate diversity. Students then develop testable hypotheses and sample the pond accordingly to evaluate their hypotheses.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Identify a variety of different macroinvertebrates inhabiting a local pond
- Describe the effect of depth on aquatic biodiversity

Inquiry Skills

- Develop working hypotheses and predictions for a given investigative question
- Design an experiment to test hypotheses
- Determine and compare the abundance of macroinvertebrates inhabiting different depth zones in the pond
- Decide whether data support hypotheses

Lab Skills

- Collect aquatic invertebrates using nets and other collecting tools
- Use a dissecting microscope
- Use identification guides

Communication Skills

- Write a scientific lab report that accurately summarizes the experiment

National Science Education Standards: Content Standards A:1:1, A:1:2, A:1:3, A:1:4, A:1:5, A:1:6, A:2, and C:4:3 (see Appendix B)

Materials

Field

- Collecting materials such as nets (Ward's D-Frame Aquatic Net #10 W 0620 recommended), closable jars, etc.
- Buckets for holding organisms and pond water
- Enamel or plastic pans for sorting and viewing aquatic invertebrates
- Thermometers (optional)
- Meter sticks—several
- Hip waders—a pair per sampling team
- Rubber boots—for use by nonsampling students
- Tweezers for moving organisms within the containers

Materials

In Lab

- Dissecting microscopes
- Tweezers
- Probes
- Plastic petri dishes for holding organisms
- Identification guides (**see attached bibliography** for suggestions)
- Plastic pipettes/eyedroppers
- Calculator
- Graph paper (**see the graph paper** form in Appendix C, "Student•Graphing Data 22")

Instructor Preparation

Before the lab, the instructor will have to identify a nearby pond that is accessible. A landowner may need to be contacted for permission to use the pond. The main accessibility concerns include proximity to campus or school, parking of vehicles, a pond shoreline that accommodates the group size, and varying water depths to accommodate the experimental design (**see Procedure Part A**).

The other concern to resolve is the time allotted for the activity. Ideally, the field and lab components of this investigation (Procedure Parts B and C) would occur on the same day. It is possible to do the field component on one day and the lab component the next day if there are time constraints. The in-lab and field materials listed will need to be collected and readied before the investigation begins.

As this lab requires that students identify macroinvertebrate pond organisms using identification guides, it is recommended that instructors decide ahead of time which taxonomic level of identification would be most appropriate for their students. In general, it is recommended that introductory biology students identify to the level of order. However, some advanced groups may be capable of identifying to the taxonomic level of family.

Activator/Connector

Recall the steps in the scientific process. What parts of this process were used in Pond Investigation I?

Recall your observations of the pond in Pond Investigation I. In what parts of the pond were the aquatic invertebrates collected?

If the pond is an ecosystem, brainstorm some of the "mini" ecosystems or habitats within a pond.

Activity Sequence

1. Preview the investigation, its purpose, background, and learning outcomes

2. Present and discuss the investigative question (Procedure Part A)

3. Lead students in making a hypothesis and predictions (Procedure Part A)

4. Lead students in developing an experimental procedure (Procedure Part A)

5. Carry out the experimental procedure at the pond (Procedure Part B)

6. Identify organisms in the lab (Procedure Part C)

7. Data analysis (Procedure Part D)

8. Follow-up discussion questions

Procedure

Part A: Designing the Investigation

Procedure Part A could be carried out at the pond site or in the classroom. Remind students that there are checkboxes in the Procedure sections of their handouts to track their progress in completing the lab.

1. Present the investigative question: *Does pond depth have an effect on aquatic invertebrate diversity?* (The pond's slope and shoreline characteristics will determine what depths are appropriate to test. Possible depths may be 0–15 cm, 15–30 cm, 30–60 cm, or 0–1 meter, 1–2 meters, etc.)

Before proceeding, ask students to identify the dependent variable (the aquatic invertebrates) and the independent variable (the depths) in the question.

Investigative Question Rationale: Students may ask why this is important to know about a pond. If appropriate, share with them that this information may help fisherpersons understand what flies to use in different parts of the pond, or may yield important information on how to minimize human impact on the microhabitats of ponds.

2. Lead students in developing a working hypothesis and predictions. Ask the students to discuss, generate, and record a working hypothesis and specific predictions based on their preconceptions and knowledge of the pond ecosystem. It may help to use to an "if–then" format to state the hypothesis and predictions. Share and discuss the various hypotheses and predictions as a class.

3. Lead students in designing and carrying out an investigative protocol. Ask students to devise an experimental procedure that will test their hypothesis and predictions. Remind them to include the specific equipment necessary to run the protocol. We suggest that teams of two to three students devise the experimental procedure. The entire class can then share and critique each team's design. Both the teamwork and the class discussion will ideally provoke higher-order thinking and investment in the inquiry that follows.

As a class, agree on a procedure that is testable and fits within the time constraints present. The instructor should decide how many field teams are optimal to run the procedure. It is recommended that as many students as possible be engaged directly in the sampling. Accessibility or equipment limitations, however, may place restrictions on how many students can carry out the actual sampling required at the pond. If this is the case, the rest of the class can act as support in the field and identifiers in the lab.

Summary: At the end of Part A, the class should have a clear procedure for addressing the investigative question, as well as a set of varying hypotheses and predictions as to the outcome of the inquiry.

Part B: Carrying Out the Investigation in the Field

If this session takes place on a different day than Part A, review the investigative question and selected student hypotheses.

1. Ready all relevant field equipment and materials and take students to the pond under study.

2. Give students a chance to revise their hypotheses after observing the sampling areas and depths more carefully.

3. Carry out the procedure designed by the class to test the investigative question. It is important to model proper collecting protocol so that the results are valid. Emphasize careful work and consistent

collection methods. Clearly label all containers holding aquatic invertebrates with the depth where the sample was found.

Part C: Lab Work

1. It may be useful to split up the class into groups based on sampling depths. The students begin to identify the aquatic invertebrates found at each depth. Create a running list of organisms identified for each sampling depth on a poster or chalkboard so all students may add to the list.

Discuss issues like identification reliability (can the identification skills of the class be trusted?), total numbers of organisms vs. diversity (there may be more overall numbers of organisms in one sample but more diversity in another—what does this mean?), complete analysis of sample (are students seeing and identifying all organisms present in each sample?), and other procedural issues as they arise.

2. Ask students to record organisms with high overall numbers and low overall numbers.

3. At the end of the identification period, each student will need to record all species identified for each sampling depth.

Part D: Data Analysis

Lead students in analyzing the data:

1. List taxa found at all depths.

2. List taxa found only at a single depth and the depth at which they were found.

3. For each depth, calculate the percentage of the total number of different taxa which were unique to that depth.

4. For each depth, calculate the percentage of the total number of different taxa which were the same in all depths.

5. Graph the class data to show numbers of organisms unique to a depth and numbers of organisms overlapping depths.

Follow-up Discussion Questions

Review:

Compare and discuss results from the data analysis.

1. Which organisms overlapped at each depth?

2. Which organisms were unique to each depth?

It is recommended that these questions be explored visually through a Venn diagram or by color coding the list of organisms found.

Interpretive:

3. What conclusions can students draw from their data? Did the data support their hypotheses and predictions?

4. Based on the data and observations, ask students to develop one or more new hypotheses as to why the different depths had the diversities observed.

5. Based on the data and observations, ask students to develop one or more new hypotheses as to why there were different numbers of individuals for the different taxa.

6. What are the possible sources of error in the data?

Reflective:

7. What did you learn about pond ecology?

8. What did you learn about the nature of scientific inquiry?

9. What aspects of this investigation were most suited to your learning style?

10. What aspects of the lab were most challenging?

Formative Assessment

- Students will demonstrate their abilities to develop and test hypotheses through developing and discussing with each other the lab protocol. They will demonstrate their abilities to compare the abundance of macroinvertebrates and evaluate hypotheses orally during the discussion that follows the lab procedure.

- Students will demonstrate their use of proper lab and field techniques during the Procedure components of the lab.

- Students will show their skills with observing and identifying aquatic invertebrates during the laboratory-based component of the investigation.

- Students will show their abilities to reflect on the ecological conditions that affect a pond's biological community through their oral participation in the discussion that follows the investigation.

Summative Assessment

- Assign students to write a report using the Lab Report Template **on page 163**. Consider using a rubric, such as An Example of a Rubric for an Inquiry-Based Biology Laboratory Report **on page 130**, to assess overall student mastery of the learning outcomes.

- Choose one component of the investigation for students to write about. For example, ask them to write an explanation of the working hypothesis and revision of that hypothesis based on the results of the investigation. Use components of the inquiry-based lab report rubric to assess mastery of the relevant learning outcomes.

Suggestions for Extended Learning

Ask students to generate additional investigative questions, hypotheses, and experimental procedures concerning the ecology of the pond.

Suggested Identification Books and Web Resources

Chu, H. *How to Know the Immature Insects.* Dubuque, IA: Wm. C. Brown Company Publishers, 1949.

Lehmkuhl, D. *How to Know the Aquatic Insects.* Dubuque, IA: Wm. C. Brown Company Publishers, 1979.

McCafferty, P. *Aquatic Entomology: The Fisherman's and Ecologists' Illustrated Guide to Insects and Their Relatives.* Sudbury, MA: Jones and Bartlett Publishers, 1981.

Needham, J. *A Guide to the Study of Fresh-Water Biology.* San Francisco: Holden-Day, 1962.

Peckarsky, B., P. Fraissinet, M. Penton, and D. Conklin Jr. *Freshwater Macroinvertebrates of Northeastern North America.* Ithaca, NY: Comstock Publishing Associates, 1990.

Reid, G. *Pond Life*. Golden Guide series. New York: St. Martin's Press, 2001.

Voshell, R. *A Guide to Common Freshwater Invertebrates of North America*. Blacksburg, VA: McDonald & Woodward Publishing Company, 2002.

http://www.microscopy-uk.org.uk/pond/. Online information and identification resource for pond organisms, with great photos.

8 ACTIVITIES: EVOLUTION

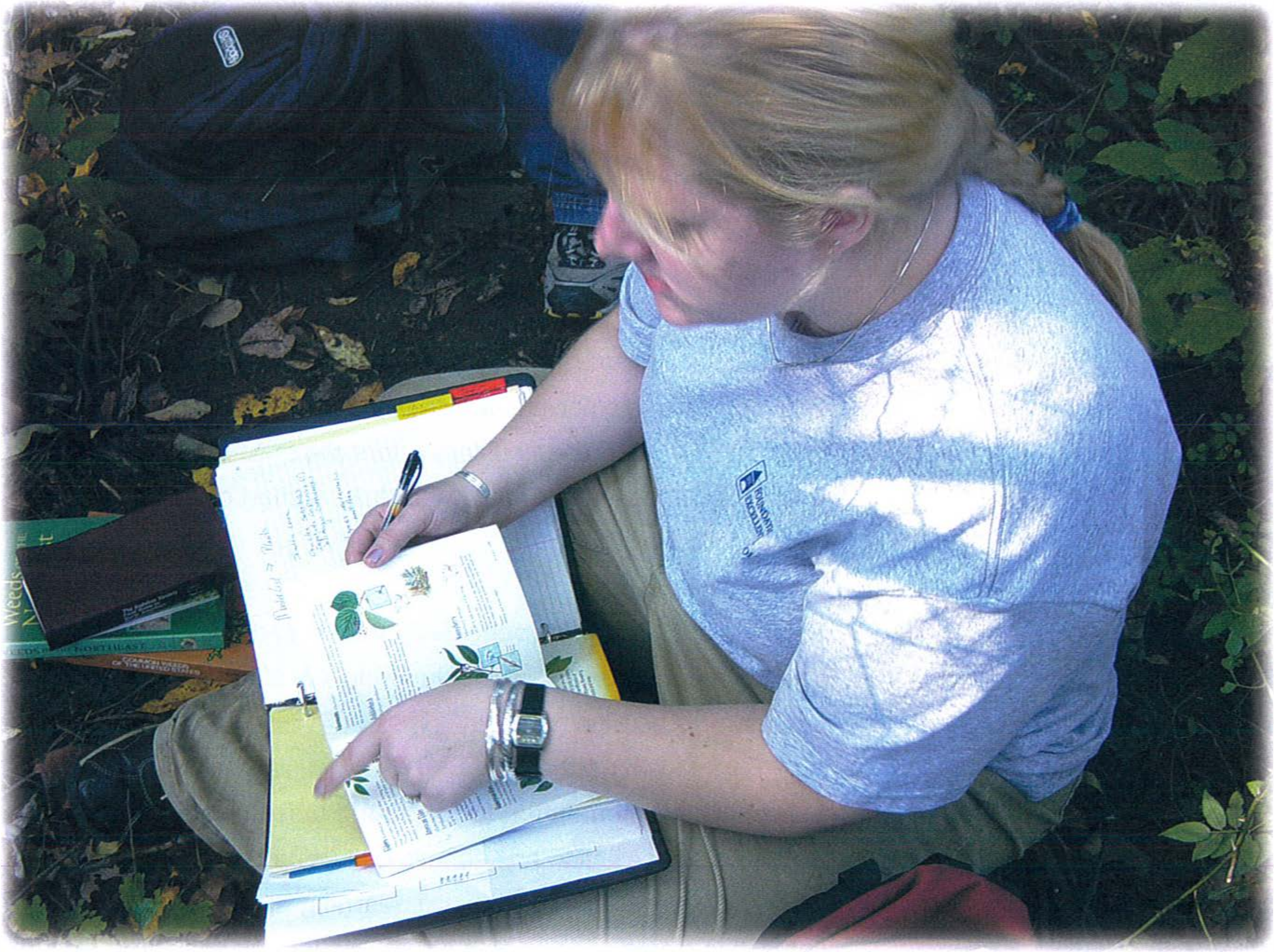
Introduction

This section contains three activities that fall under the content area of evolution. They are not intended to be used in the particular sequence in which they are presented. Instructors are encouraged to use them in any sequence that fits their curriculum. A short description of each activity follows.

Science and Religion (page 237). Students discuss and compare science and religion as ways of knowing. No student handout is provided for this activity.

Mussel Beach Simulation (page 240). Students carry out a simulation of natural selection and genetic drift using beads and fabric. The activity demonstrates an inductive learning approach to these concepts. It is also designed as a structured inquiry activity, in that the instructor offers explicit instructions and procedures, yet students are pressed to draw their own conclusions. A complete student handout is provided in Appendix C, "Student • Mussel Beach Simulation."

Phylogenetic Trees (page 256). In this lab-based activity, students learn about phylogenetic trees and about interpreting the evolutionary relationships of fish species using gel electrophoresis. It is designed as a structured inquiry activity, in that the instructor offers explicit instructions and procedures, yet students are pressed to draw their own conclusions. A complete student handout is provided in Appendix C, "Student • Phylogenetic Trees."



Science and Religion

Time Required: 60 minutes

Summary

In this activity, students will discuss and write about their thoughts on the relationship between science and religion. It is assumed that instructors have previously discussed the nature of science with students and are using this activity as an introduction to a unit on evolution. Students first discuss their ideas in small groups, then share them with the whole class.

National Science Education Standards: Content Standards G:2:1, G:2:2, and G:2:3 (see Appendix B)

Materials

- Pencil
- Writing paper
- Poster paper
- Colored markers

Learning Outcomes

After completing this activity, students will be able to:

Content

- Describe the nature of science and scientific inquiry
- Distinguish between fact and theory
- Identify key differences between science and religion

Communication Skills

- Respectfully contribute to small- and large-group discussions on the nature of science and religion
- Write about the differences between science and religion

Instructor Preparation

This activity is meant to be an activator for a unit on evolution in order to motivate student interest in that subject. It is written based on the assumption that an instructor has previously discussed the nature of science and has already defined terms such as *fact, theory,* and *scientific method.* If these broader aspects of science have already been discussed, instructors may wish to conduct a brief review first. This activity may also help the instructor to see where students are in their thinking and to identify anyone who is uncomfortable with the subject of science and religion.

The controversy between science and religion need not be presented as a conflict at all. When the two types of knowledge are examined closely, one may discover that they are two different modes of perceiving the world and are not necessarily in competition with one another, as often presented in creationist arguments, and even by scientists.

This is not intended as a graded assignment, because the main purpose of the activity is to get students thinking and talking, not to evaluate what they have to say. Each student may be given the option to "pass" on the large-group participation, but not on the small-group sharing. It is important for the instructor to lay some ground rules for discussion that ensure a nonthreatening and respectful environment. For more on structuring and leading discussions, see "Discussion" **on page 107**.

The teacher should develop a set of questions for use in this activity. For example:

- Do science and religion offer similar or different kinds of knowledge? Explain.
- Where does scientific knowledge come from?
- Where does religious knowledge come from?
- How does each kind of knowledge change?

Instructors may also wish to do some background reading (**see Resources** at the end of this activity) to get a sense of where the scientific community stands on this topic, or to gain some perspective on their own thoughts or feelings.

Activator/Connector

Probe students' background knowledge of evolution and religion. Ask if the students have ever been involved in or listened to a discussion on their relationship.

Activity Sequence

1. Preview the activity, its purpose, and learning outcomes

2. Individual written responses to questions

3. Small-group discussion

4. Large-group discussion

5. Suggestions for extended learning

Procedure

1. Discuss ground rules for conducting a respectful discussion.

2. Present questions to the students and allow several minutes for them to write individual responses.

3. Arrange small groups of two to three students each to share and discuss the responses. The instructor may or may not wish to participate in the discussions at this point, depending upon the level of support students need and whether misconceptions arise.

4. Have each group write its individual or group responses to the questions on poster paper. Some students may prefer to put their ideas into graphic form with cartoons or drawings, or similar displays.

5. Open the discussion up at the class level. Again, at this point the instructor may or may not wish to participate, depending upon the needs of the class and the level of student comfort. For example, discussion may lead to a debate on the subject, which may cause some students to feel uncomfortable. If students do not suggest the following ideas, the instructor should bring them into the discussion:

- Science is based on evidence; religion is based on revelation or tradition.
- Science is open to revision; religion generally is not.
- Studying science and evolution does not mean changing one's religious beliefs.
- Science and religion are compatible.

6. Display each group's responses in a prominent location (e.g., a wall) and give students time to read them.

Follow-up Discussion Questions

Review:

1. Ask students to share their key learning from the activity.

Reflective:

2. Students can discuss what they liked and/or disliked about the activity.

3. Student can consider how well they were able to communicate their thoughts on science and religion: in small-group discussions? in large groups? in writing?

Formative Assessment

- Students will demonstrate their understanding of the nature of science and the differences between science and religion during both the small-group and large-group discussions.

- Students will demonstrate their ability to distinguish between fact and theory during the large-group discussion.

- Students will show their facility in contributing their ideas respectfully during small-group and large-group discussions.

Summative Assessment

This activity is not designed to be graded, but after the discussion, some instructors may wish to assign a summative "reflection" paper, based on the learning outcomes, in order to reinforce the activity.

Suggestions for Extended Learning

If the instructor wishes to extend the activity to include specific questions about evolution, here are some suggested questions:

- Define evolution.
- What is your understanding of evolution as a process?
- What are your thoughts and/or feelings on evolution?
- Are evolution and religion compatible or incompatible? Explain.

Here are some keys ideas regarding evolution that instructors may wish to present:

- Evolution is a cornerstone of biology, not a "belief."
- Evidence is the key factor in evolution.
- Understanding evolution is important for science literacy.

Resources

Alters, B. 1998. Stephen J. Gould: An interview. *The American Biology Teacher* (April): 272–75.

Meadows, L., E. Doster, and D. Jackson. 2000. Managing the conflict between science and religion. *The American Biology Teacher* (February): 102–7.

Mussel Beach: A Simulation of Evolutionary Change*

Time Required: 2½–3 hours

Summary

In this lab, two types of evolutionary change—natural selection and genetic drift—will be investigated with simulations involving two different populations of mussels. In one population, the *oystercatchers* are predatory birds that simulate the natural selection mechanism as they visually "hunt" for mussels in the "habitat." In the other population, the *driftwood logs* simulate genetic drift in the random manner by which they "kill" mussels upon the shore. The class is divided into teams that carry out one or the other simulation.

This activity is designed to introduce the concepts of natural selection and genetic drift in an inductive manner: students explore the concepts experientially through the simulation, and then are introduced to the key vocabulary after they have run the simulation. For more on inductive teaching, **see page 102**. Individual instructors may revise the activity to be deductive if they wish. This lab simulation is best used after students have had a solid foundation in genetics.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Define the concepts of natural selection and genetic drift
- Differentiate between natural selection and genetic drift with respect to how they influence evolutionary change in small populations

Inquiry Skills

- Display data in both tabular and graphic form
- Compare and contrast related sets of data and draw conclusions
- Identify sources of experimental error

Communication Skills

- Write a scientific lab report that summarizes the experimental simulation

National Science Education Standards: Content Standards A:1:1, A:1:3, A:1:4, A:1:6, A:2, and C:3:1 (See Appendix B)

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* The basic premise and some aspects of the procedure for this lab were adapted, with permission, from T. Marat and S. Rissing, "Exploring Genetic Drift and Natural Selection through a Simulation Activity," in *The American Biology Teacher* (Nov/Dec 1998), 681–83.

Materials

Each team of two students needs the following (see Figure 8.1):

- the student handout that contains the procedure and data form (**see Appendix C**, "Student•Mussel Beach Simulation")
- a container with 40 mixed beads—10 beads in each of 4 colors (the 40 beads represent a population)
- a piece of multicolored fabric with a complex pattern, about 50cm x 30cm (this represents the habitat)
- 4 small containers, each with beads of one of the four colors (about 40 beads in each container)
- graph paper or graph templates
- Optional: colored markers for making graphs (same colors as beads)
- 2 labeled petri dishes:
  —"survivor" dish
  —"graveyard" dish

Driftwood log (genetic drift) teams need, in addition,

- masking tape, sticky side out, wrapped around 3 pencils

Instructor Preparation

Materials Set-up

1. Have the containers of mixed beads ready. Each team needs to have one "population" container with 40 beads—10 of each of the 4 colors chosen. For best results, the beads should be approximately 3–4 millimeters in diameter. For the natural selection aspect of the simulation to work best, one bead color should blend in well when set against the fabric background chosen.

Figure 8.1. Some of the materials used in the Mussel Beach Simulation: Containers with beads that represent the mussels; pencils that are taped sticky-side-out representing the driftwood logs; and petri dishes labeled "survivors" and "temporary grave" that help manage the counting of beads

2. Prepare and make ready for distribution to each team 4 additional containers holding approximately 40 beads each in one of the 4 colors chosen.

3. Each *driftwood log team* needs 3 pencils covered in masking tape with the sticky side out. One way to make them is to roughly measure out two pieces of tape as long as the pencil. Then tape the two pieces together side by side. Finally, wrap this one piece around the pencil with the sticky side out. A fresh taped pencil is needed for each round, because the tape loses its stickiness and becomes less effective at picking up beads.

4. Each group's "habitat" must have the same background pattern.

5. Have the 2 petri dishes for each group labeled ("graveyard," "survivors") to keep track of beads in the various stages of the simulation.

6. Prepare and copy the student handout for this activity, found in Appendix C, "Student•Mussel Beach Simulation." It includes learning outcomes, investigative question, hypothesis/predictions, procedure, data table, etc.

7. Prepare and copy graph template(s) to distribute to students for recording data trends.

8. Prepare a brief written agenda that gives an overview of the lab.

Activator/Connector

Ask students: Pretend that you are a mussel living on the shoreline. List some ways that you might be killed.

Discuss the responses. If appropriate, connect to population ecology concepts like density-dependent and density-independent population limiting factors.

Activity Sequence

1. Instructor previews lab purpose, general background, and learning outcomes

2. Instructor models both simulations

3. Students run simulations in teams and record data

4. Students graph their own data in teams

5. Students share and copy all data collected

6. Follow-up discussion questions, including naming the types of evolutionary change

Procedure

1. Organize student teams. Have students work in pairs, each pair assigned to either "oystercatcher" or "driftwood log." In order to have meaningful results to analyze, at least two student teams should be assigned to each simulation (four teams total); ideally, an equal number of teams will perform each simulation. Have students collect the materials and spread out the "habitat" in their working areas.

2. Model the procedure. It is essential to show students a thorough and careful run-through of the simulation in order for this activity to be successfully completed.

Have students gather around an area where you have laid out the lab materials. Run through enough of the simulation for both oystercatchers and driftwood logs that students understand the procedure and how to enter the data on the data table properly. Ask that they follow along with the procedure as described in their student handouts as they observe the simulation.

3. Present the investigative question: *What is going to happen to each of the four mussel/bead subpopulations after running the oystercatcher and driftwood log simulations?*

4. Have students record their predictions and hypotheses. Ask students to make predictions and hypotheses based on the following prompts. Get them to consider what will happen to each of the four colors when they run the simulation, and why. Discuss responses before proceeding.

> **Oystercatcher prompt:** What do you think will happen to each of the four colors of beads

when the oystercatcher simulation is performed? (prediction)

What is the basis for the prediction? (hypothesis)

Driftwood Log prompt: What do you think will happen to each of the four colors of beads when the driftwood log simulation is performed? (prediction)

What is the basis for your prediction? (hypothesis)

5. Have student teams run the simulation and collect data. Students should run the simulations and collect data according to the following procedures described for each simulation. They should use the data table for recording data. They can refer to their own handouts and to the instructor for support. Suggest to students that they use the checkboxes in their handouts to keep track of their progress.

PROCEDURE FOR OYSTERCATCHER SIMULATION

(1) Working in pairs, students collect the materials and spread out the fabric.

(2) Identify students' roles in the team: The *oystercatcher* hunts the mussels; the *habitat manager* manages the fabric and bead counts.

(3) The habitat manager sprinkles the 40 beads onto the fabric and spreads them evenly.

(4) The oystercatcher picks out 30 beads in a predatory manner (one at a time) by looking at the fabric and taking the first bead that stands out, then looking away between each "hunt" **(see Figure 8.2)**.

(5) The oystercatcher puts the bead victims in the "graveyard" dish. The habitat manager counts them carefully as they are hunted, until 30 are removed from the fabric and placed in the dish.

(6) Hunting stops when 10 survivors are left on the fabric.

(7) The remaining 10 bead survivors are removed from the fabric and placed in the "survivor" dish. The number of each color is counted and recorded in the data sheet provided.

(8) The number of each survivor color is multiplied by 3 and the results are put in the data sheet. The total of the four colors should add up to 30.

(9) The number of survivors of each color is added to the corresponding total from step 8 and recorded in the Totals column of the data sheet. The total number of all four colors should add up to 40.

(10) Then, the numbers of beads of each color shown in the Totals column are taken from the four single-color bead containers,

Figure 8.2. A depiction of Oystercatcher Procedure step 4: A student hand (the oystercatcher) "hunting" beads (the mussels) spread out over the fabric (the rocky coastline habitat)

and 40 beads are once again scattered onto the fabric to start round two.

(11) Steps 4 through 10 are repeated two more times for a total of three rounds.

PROCEDURE FOR DRIFTWOOD LOG SIMULATION

(1) Working in pairs, students collect the materials and spread out the fabric.

(2) Identify students' roles in the team: The *driftwood log* "crashes" a pencil onto the fabric. The *habitat manager* manages the fabric and bead counts.

(3) The habitat manager sprinkles the 40 beads onto the fabric and spreads them evenly.

(4) With eyes closed, the driftwood log gently rolls or drops the taped pencil randomly into the "habitat" and removes the beads that stick to it, *watching out for escapees that get knocked off the fabric and putting them back on the "habitat"!* (**See Figures 8.3 and 8.4**)

(5) The beads from the pencil are put in the "graveyard" dish and counted carefully as they are "killed," until a total of 30 are removed. It may take a few rolls of the pencil to achieve the precise number of 30 beads. If a roll yields a cumulative number "killed" larger than 30, beads from that roll should be put back on the fabric and the pencil rerolled, if necessary repeating this procedure of replacing and rerolling until exactly 30 beads have been removed.

(6) The habitat should be checked to make sure that 10 survivors are left.

(7) The remaining 10 bead survivors are removed from the fabric and placed in the "survivor" dish. The number of each color is counted and recorded in the data sheet provided.

Figure 8.3. In Driftwood Log Procedure step 4, the taped pencil (the driftwood log) is being randomly tossed onto the fabric (the rocky coastline habitat)

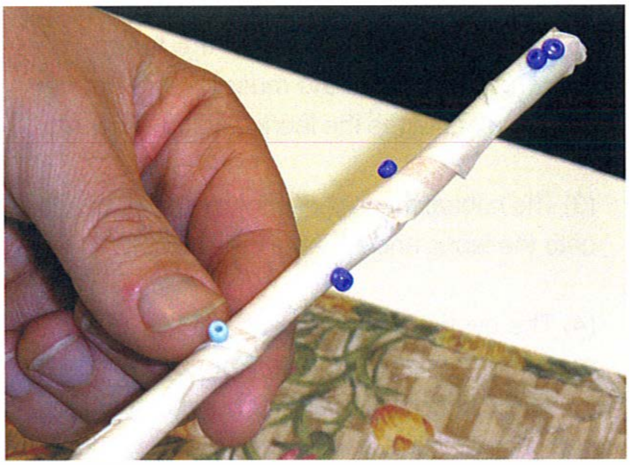


Figure 8.4. In Driftwood Log Procedure step 4, the beads (the mussels) stuck to the taped pencil are about to be placed in the "graveyard"

(8) The number of each survivor color is multiplied by 3 and the results are put in the data sheet. The total of the four colors should add up to 30.

(9) The number of survivors of each color is added to the corresponding total from step 8 and recorded in the Totals column of the data sheet. The total number of all four colors should add up to 40.

(10) Then, the numbers of beads of each color shown in the Totals column are taken from the four single-color bead containers, and 40 beads are once again scattered onto the fabric to start round two.

(11) A new taped pencil is obtained, and steps 4–10 are repeated two more times for a total of three rounds.

Data Tables

Sample Data. This sample data uses the following four bead/mussel colors: green, blue, white, and purple.

First, count the number of ***survivors*** of each color and enter that number in the Survivors column below (Procedure step 7).

Second, multiply the number of survivors by 3 (Procedure step 8).

Third, add the number of survivors to the total from the previous column.

The total is the number of beads that get placed on the fabric for the next round (should be a total of 40) (Procedure step 9).

Survivors			Totals
3 Green	Survivors x 3 = 9	9 + 3 (Survivors) =	12
3 Blue	Survivors x 3 = 9	9 + 3 (Survivors) =	12
3 White	Survivors x 3 = 9	9 + 3 (Survivors) =	12
1 Purple	Survivors x 3 = 3	3 + 1 (Survivors) =	4

Mussel Beach Data

Round One

Survivors			Totals
__ Green	Survivors x 3 =	____ + ____ =	
__ Blue	Survivors x 3 =	____ + ____ =	
__ White	Survivors x 3 =	____ + ____ =	
__ Purple	Survivors x 3 =	____ + ____ =	

Place the number of beads of each color indicated in the Totals column back in the habitat for the next round.

Round Two

Survivors			Totals
__ Green	Survivors x 3 =	____ + ____ =	
__ Blue	Survivors x 3 =	____ + ____ =	
__ White	Survivors x 3 =	____ + ____ =	
__ Purple	Survivors x 3 =	____ + ____ =	

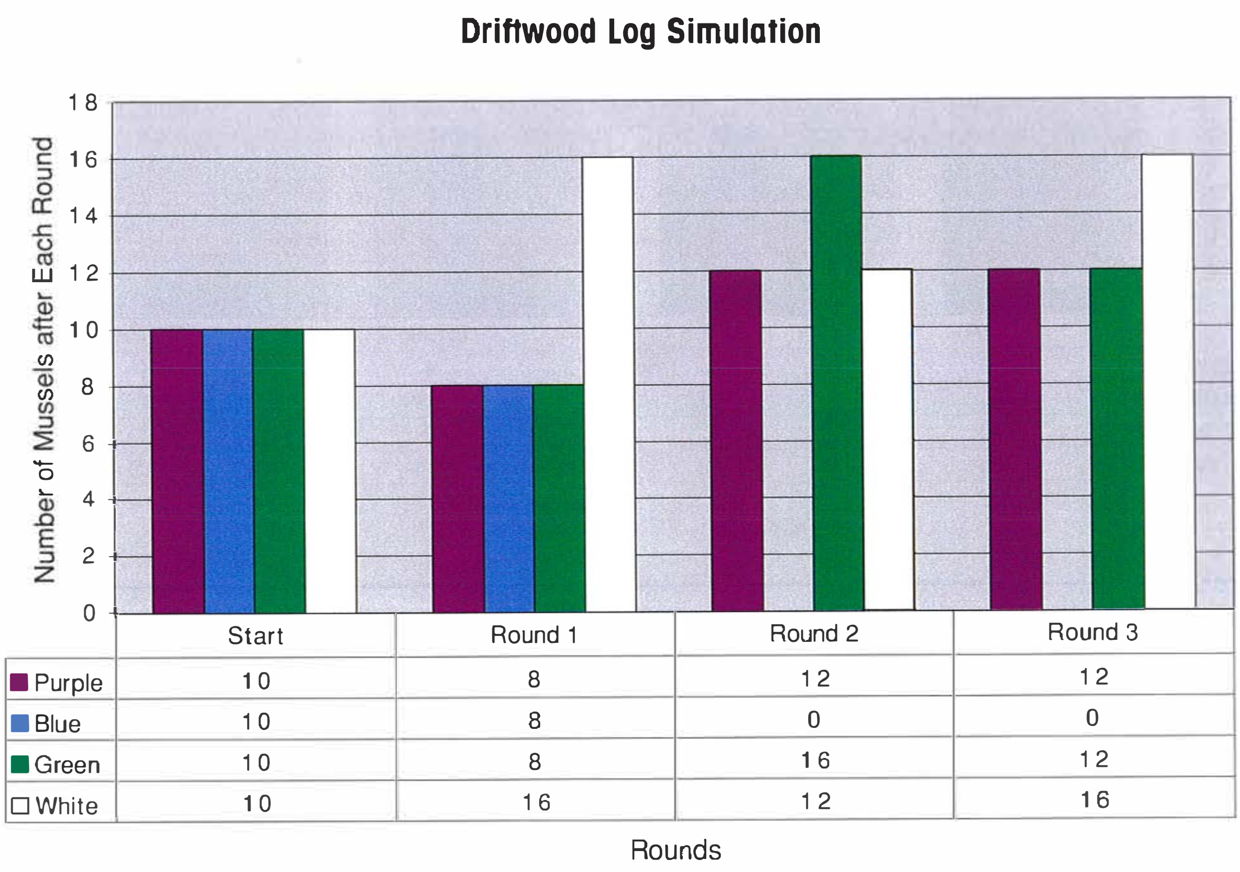
Place the number of beads of each color indicated in the Totals column back in the habitat for the next round.

Round Three

Survivors			Totals
__ Green	Survivors x 3 =	____ + ____ =	
__ Blue	Survivors x 3 =	____ + ____ =	
__ White	Survivors x 3 =	____ + ____ =	
__ Purple	Survivors x 3 =	____ + ____ =	

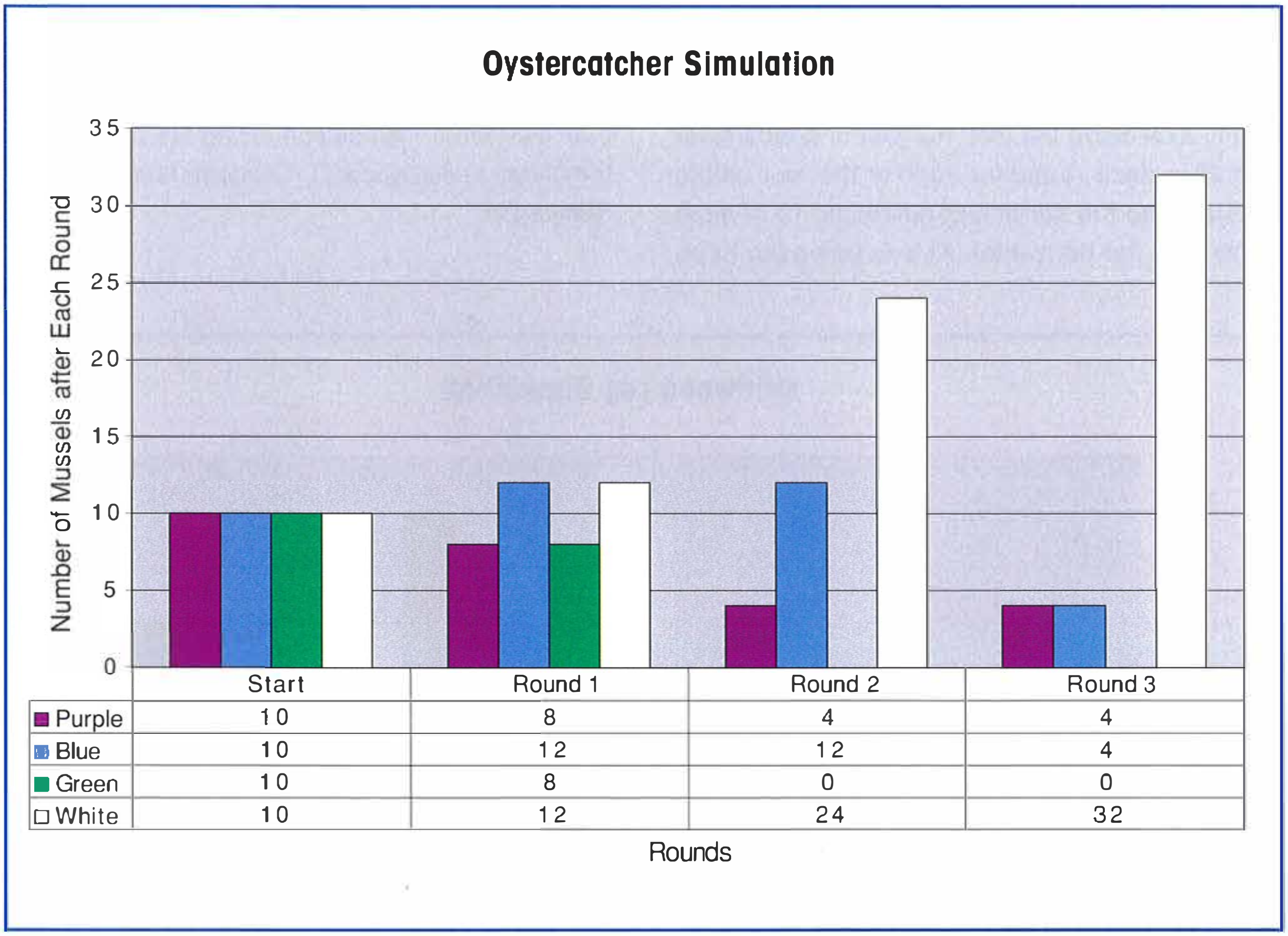
Do not place any more beads back on the fabric; the simulation ends after three rounds.

6. Instruct students on graphing results. Show students an example of how to display the results (after three rounds) in a bar graph, with the vertical (Y) axis being the total number of beads/mussels after each round for each of the four colors (include also the starting populations, 10 of each color), and the horizontal (X) axis being the three rounds plus "round zero," the starting point. **See Figures 8.5 and 8.6** for examples of a graph for each simulation. Ask students to make a graph for their own team's simulation, using the blank graph templates in Appendix C, "Student•Mussel Beach Simulation."



	Start	Round 1	Round 2	Round 3
🟪 Purple	10	8	12	12
🟦 Blue	10	8	0	0
🟩 Green	10	8	16	12
☐ White	10	16	12	16

Figure 8.5. Sample Driftwood Log graph



	Start	Round 1	Round 2	Round 3
🟪 Purple	10	8	4	4
🟦 Blue	10	12	12	4
🟩 Green	10	8	0	0
☐ White	10	12	24	32

Figure 8.6. Sample Oystercatcher graph

7. Displaying class results. In order to facilitate a careful class discussion on the results of the simulation, we suggest the following plan: Distribute poster-size paper and colored markers associated with the specific bead colors to each student team. Ask teams to copy their bar graphs and post them in the front of the classroom. Be sure to group the graphs according to the type of simulation (driftwood log or oystercatcher).

For instructors who are using this activity and its data only as an introduction to the concepts of natural selection and genetic drift, allow the students to come up and view the data closely for a few minutes and then proceed with the follow-up discussion questions.

For instructors who require that students follow up the in-class parts of this activity with some form of outside-of-class analysis or report, arrange for students to photocopy or draw copies of graphs from other teams so that they have a complete set of data for all simulations that were run. Use the blank graph templates we have provided for each simulation in Appendix C, at the end of "Student • Mussel Beach Simulation 10, 11," if desired. Allow adequate time and support for this to take place smoothly and efficiently. When students have a complete set of data, proceed with the follow-up discussion.

Follow-up Discussion Questions

Review:

1. Compare and contrast the oystercatcher graphs for the whole class.

Student responses will vary, but ideally there will be some noticeable similarities between the oystercatcher groups. A pattern will be discernible; beads of the same color will have thrived while others will have diminished or been eliminated.

2. Compare and contrast the driftwood log graphs for the whole class.

Student responses will vary, but ideally there will be significant differences in the driftwood log graphs. No pattern should be discernible. The graphs should show the random nature of the simulation.

3. Compare and contrast the data for the driftwood logs vs. the oystercatchers.

Student responses will vary, but ideally they should show different trends when compared.

4. Compare the results to your original predictions and hypotheses for both the oystercatcher and the driftwood log simulations: Do the results support your original hypotheses and predictions? Explain.

Student responses will vary, but some students will have accurately predicted that one particular color would thrive in the oystercatcher simulation, and that the colors which thrive or decrease would be totally random in the driftwood log simulation.

5. The simulation: What does each of the simulation components represent in nature?

The beads: *mussels*
The pencil: *driftwood log*
The step of increasing the 10 survivors to 40: *reproduction*
The fabric: *coastline habitat*
The bead colors: *natural variation in mussels or subpopulations*
The elimination of bead colors: *extirpation of subpopulations*
The different rounds: *time or generations*

6. What are at least two other variables that affected how the simulation played out? Do these same variables exist in nature?

Student responses will vary. Some common responses will be the following: Oystercatcher teams: visual acuity of individual students. In nature there is variation in visual acuity among individual oystercatchers too. Driftwood log teams: the method of rolling the pencil. This exists in nature too, as logs crash in various ways onto the shoreline.

Interpretive:

7. Introduce and explain the concepts of natural selection and genetic drift. Define these terms and discuss how they apply to the simulation.

Natural selection—a mechanism for evolutionary change involving the differential survival and reproduction of certain individuals in a population based on their favorable adaptations or characteristics.

Genetic drift—a mechanism for evolutionary change involving the effects of random or chance events, usually environmental. Differential survival and reproduction is irrelevant to genetic drift.

8. What if the numbers of each mussel subpopulation were much larger—in the thousands or even millions—how would this affect the simulation?

It would be less likely that a random event like death from driftwood logs would eliminate an entire subpopulation. Genetic drift is a more powerful evolutionary force when populations are small.

9. What if the two mechanisms, genetic drift and natural selection, were *both* operating in the same simulation? Predict the outcome.

As in nature, the mussel population would be affected by many forces, not necessarily working in concert with each other. The results would be less predictable.

Reflective:

10. What did students like or dislike about the simulation?

11. How would students improve it?

12. What did this lab demonstrate to students about their learning styles? What strategies might be employed to make this lab more manageable?

Formative Assessment

- Students will show their skills in recording data during the simulation's procedure, and their skills in graphing data during the follow-up to the simulation procedure.

- Students will show their abilities to compare and contrast data sets and identify sources of experimental error during the follow-up discussion component of the simulation.

- Students will demonstrate their abilities to differentiate between natural selection and genetic drift with respect to how each influences evolutionary change in small populations during discussion following the activity.

Summative Assessment

- Ask students to complete a lab report using the lab report template **on page 163**. See also the example of a Mussel Beach Assignment Packet beginning **on page 252**.

- Ask students to write answers only to the discussion questions.

- Distribute to students the following fictitious set of data for this simulation. Ask students to review the data and take a position on whether the population is evolving by genetic drift or natural selection, or that there is not enough information to know. Collect the students' explanations and assess their abilities to draw conclusions about data.

Sample data:

	Green	Blue	White	Purple
Start	10	10	10	10
Round 1	16	8	4	12
Round 2	16	4	12	8
Round 3	8	16	12	4

Suggestions for Extended Learning

1. Students could develop a plan for a new simulation that builds on the current one. For example, include another variable besides color (e.g., size) for the bead population.

2. Research a real-life example of how natural selection or genetic drift is affecting some species (e.g., the work of Peter and Rosemary Grant on the medium ground-finch of the Galápagos Islands).

MUSSEL BEACH SIMULATION

ASSIGNMENT PACKET

Due Date: This assignment is due on **Wed 2/19**

Grade Value: It is worth 5% of your course grade, and the **late policy applies**

Assignment Overview: A laboratory report describing the purpose, methods, and findings of the Mussel Beach Simulation

Purpose: Practice with applying the scientific method of inquiry and writing a lab report

Structure: The report should have five sections, plus a title. Use the Lab Report Template on the next page for specific guidelines for writing the report.

Resources:

1. The Mussel Beach Simulation handout and notes
2. All graphs produced from class

Assessment:

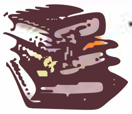
1. You will be assessed according to the assessment rubric that follows.
2. Along with the lab report, please turn in a **self-assessment** of your work using the rubric.

LAB REPORT TEMPLATE

Title: → Answers the question, "What is the **topic** of this experiment?"

Introduction:

Background:



Specific Question Being Addressed:

→

1. Explains the **concepts of natural selection and genetic drift.**
2. Describes the simulation that was run and what its purpose was (one paragraph will do).

Working Hypothesis and Predictions:

→ Should contain

1. your thoughts about how both the oystercatcher and driftwood log simulations will turn out **(predictions)** and
2. the reasoning behind these predictions (**hypotheses)**.
3. **Also** indicate here the **dependent and independent variables** operating in the simulation.

Procedure:

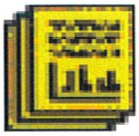
Materials:

Methods:

→ Not necessary this time around. Hooray!

Results:

Written:



Visual:

→ The results of the simulation should be summarized here:

1. **Written summary.** *This section is "just the facts!"* Do not discuss the implications of your data here.
2. **Visual format** (two driftwood log graphs and two oystercatcher graphs). Color coding of graphs is recommended.

Discussion:

→ **Address the following in your discussion section** (six questions):

1. Was each of your predictions and hypotheses supported by the results of the simulation? Explain.
2. Do the results from the oystercatcher simulation demonstrate the idea of natural selection? Do the driftwood log results demonstrate the idea of genetic drift?
3. Discussion questions 6, 8, and 9 **on pages 249 and 250** of the Instructor Guide for this activity.
4. How could the simulation be improved to make it more realistic, or to better manage the variables that affected the simulation?

ASSESSMENT RUBRIC FOR MUSSEL BEACH SIMULATION

Lab Section	Area of Assessment	Qualities of Excellent Work (full credit)	Qualities of Developing Work (partial credit)	Qualities of Incomplete Work (no credit)	Comments/Points
Title	Topic (0.5 point)	Clearly and accurately describes the topic of the experiment in one sentence	Description of topic may be missing some important element key to the experiment	Topic missing or inaccurate	
Introduction	Background Information (Natural Selection and Genetic Drift) (1 point)	Provides useful and accurate background information that sets the study in proper context	Provides some accurate background that sets the study in context, but lacks some key information	Background missing, or information does not at all describe the necessary background for understanding the study	
Introduction	Purpose/ Experimental Question (1 point)	Purpose of study is explicitly stated, and simulation is briefly and clearly summarized	Purpose of study is stated but not clearly; missing some key part of simulation summary	Purpose and/or summary missing or inaccurate	
Hypothesis	Hypothesis and Predictions (1 point)	Hypothesis and predictions stated clearly	Hypothesis and predictions included but not entirely clear	Hypothesis and predictions missing or irrelevant to study	
Hypothesis	Identification of Variables (0.5 point)	Accurately identifies the independent and dependent variables	Includes an identification of the independent and dependent variables, but one may be missing or misidentified	Missing an identification of the independent and dependent variables	
Results	Visual (graphs) (1 point)	The four graphs are appropriately titled, labeled, and easy to read and interpret	The graphs have some element (title, labels, etc.) that is absent, therefore making them difficult to read and interpret; or missing one or more graphs entirely	Graphs are missing, or tables/graphs are missing all key features (title, labels, etc.), making interpretation impossible	

Lab Section	Area of Assessment	Qualities of Excellent Work (full credit)	Qualities of Developing Work (partial credit)	Qualities of Incomplete Work (no credit)	Comments/Points
Results	Written Description (1 point)	Clearly and completely describes the most important results shown in the data; avoids interpretation; contains just the facts	Describes some but not all of the important results from the data; may include some interpretation not appropriate for this section	Most important results missing or not at all described, perhaps focusing only on interpretation	
Discussion	Six Questions (3 points)	5–6 questions are answered directly, accurately, completely, and with appropriate detail	2–4 answers lack some detail, or do not completely address question, or have some inaccuracies	Most questions not addressed, or so sparsely addressed as to be meaningless	
Self-Assessment	Rubric (0.5 point)	Completed and turned in	Partially completed and turned in, or completed without adequate attention	Not completed and turned in	

OVERALL GRADE/COMMENTS:

Phylogenetic Trees

Time Required:

Day 1:

- Instructor prelab preparation—1 hour
- Class time—2 hours
- Postlab follow-up—1 to 2 hours

Day 2:

- Class time—45 minutes

Summary

Evolutionary relationships between organisms can be determined based on how similar they are in morphology, behavior, biochemistry, and molecular and other characteristics. The greater the number of characteristics that are shared, the greater the likelihood that two organisms have a common ancestor. In this lab, students will compare habitat, anatomy, and diet of seven fish species to develop hypotheses of their evolutionary relationships. Then students will compare protein banding patterns in these species, using gel electrophoresis, to test their hypotheses and develop a new phylogenetic tree they can compare to the hypothesized tree. This lab is best used at the end of an evolution unit and after the genetics unit has been covered, so that students will already be familiar with concepts such as descent with modification and evidence for evolution, and with vocabulary such as *protein, mutation,* etc.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Describe the structure and purpose of phylogenetic trees
- Construct a phylogenetic tree (or trees) that hypothesizes the evolutionary relationships among seven fish species based on several criteria, including habitat, anatomy, diet, and protein electrophoretic banding patterns

Inquiry Skills

- Interpret elecrophoretic banding patterns
- Decide whether data support hypotheses

Lab Skills

- Load samples into a gel
- Prepare solutions for protein electrophoresis (optional)

Communication Skills

- Write a scientific lab report that accurately summarizes the experiment

National Science Education Standards: Content Standards A:1:1, A:1:4, A:1:5, A:1:6, A:2, C:3:3, C:3:4, and G:2:3 (see Appendix B)

Materials

Amounts provided are for running one gel; if more than one gel will be used, amounts should be adjusted accordingly. *It is important to note that the cost of materials for this lab is significant. The reagents for six gels cost $144. A set consisting of one chamber, comb, casting tray, and power supply costs $189.*

- Solutions containing an isolated protein mixture, one for each of the seven fish species listed, and a protein size standard solution (all 100 μl in small screw-top tubes)*:

  1. Catfish (*Ictalurus* spp.)
  2. Cod (*Gadus* spp.)
  3. Flounder (*Paralichthys* spp.)
  4. Halibut (*Hippoglossus* spp.)
  5. Perch (*Perca* spp.)
  6. Swordfish (*Xiphias gladius*)
  7. Tuna (*Thunnus* spp.)
  8. Protein size standard solution

- 1.6 g protein gel agarose powder*
- 100 ml Tris-glycine-SDS electrophoresis buffer, 5X concentrate*
- 500 ml Coomassie protein stain solution*
- 100 ml Coomassie destain solution, 5X concentrate*
- Casting tray with 8-lane comb
- Electrophoresis power supply, electrodes, and chamber
- Boiling water bath
- Small-tube rack
- Micropipetter
- Staining tray
- Protective goggles and gloves
- Pegboard
- 2 balls of different sizes (e.g., marble and golf ball)
- Student lab handout
- Books about fish (optional)

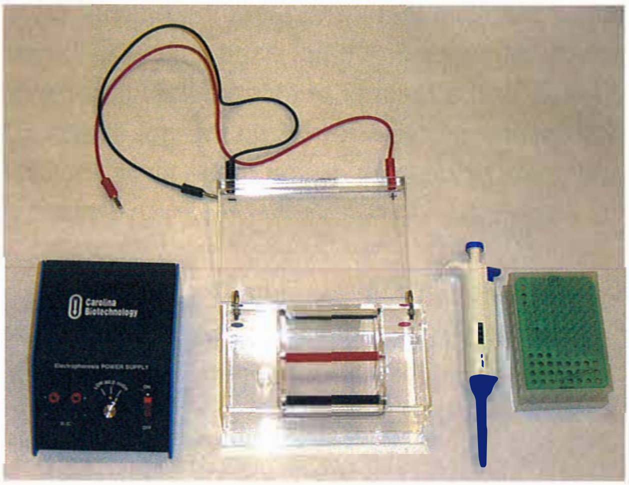


Figure 8.7. Some of the materials needed to carry out the fish phylogeny activity: (*left to right*) electrophoresis power supply; casting tray; micropipetter; small-tube rack

Figure 8.8. More materials needed to carry out the fish phylogeny activity: (*left to right, top*) protein gel agarose powder; Coomassie protein stain solution; Coomassie destain solution; Tris-glycine-SDS electrophoresis buffer; (*bottom*) protein samples for various fish species

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* Available in *Fish Protein Fingerprinting on Agarose Gels Kit* from Carolina Biological Supply Company

Instructor Preparation

1. Decide on the number of gels needed for the lab. The authors suggest using one gel per eight students, so that each student has the opportunity to load one lane. In this way, the number of gels used can be limited, to save cost. (If additional students are in the class, the number of gels can be increased accordingly.) It is also suggested that a minimum of two gels be used for the activity, to provide replication and to increase the chances of obtaining a readable gel.

2. Prepare the following solutions (can be done the day before the lab):

- 500 ml of 1X Tris-glycine-SDS buffer (add 400 ml of distilled H_20 to 100 ml of 5X buffer)
- 40 ml of agarose solution at a 4% wt/vol concentration (1.6 g agarose powder per 40 ml 1X Tris-glycine-SDS running buffer). Use a stir/heat plate or boiling water bath to dissolve the agarose (a microwave can be used to save time, but may result in an increased number of bubbles in the gel)
- 500 ml Coomassie destain 1X solution (add 400 ml of distilled H_20 to 100 ml of 5X destain)

3. After allowing the melted agarose to cool slightly (about 5 minutes), pour it into a casting tray containing an 8-lane comb (thin gels work better). (**See Figure 8.9**)

4. After the gel has set (about 10 minutes), remove the comb.

5. Prepare a boiling water bath in a container that is large enough to hold the small-tube rack. Do this with enough time before the start of the lab to ensure that the water is boiling when the lab begins.

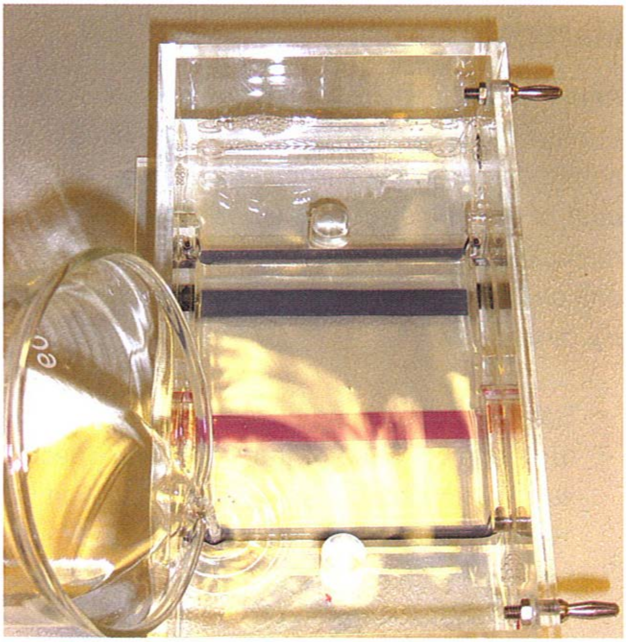


Figure 8.9. The gel being poured into the casting tray

6. It is possible that throughout the activity there will be some waiting time, especially with larger classes or if a teacher decides to have students wait for the proteins to run on the gel. Ideas for additional discussion during these times include the following:

- Give students more details about the fish species being studied (e.g., their habitat; how they are important economically, socially, or ecologically)
- Have students construct a food web or food chain based on field guides and other informational books about fish provided by the teacher

Activator/Connector

- People often look similar to members of their own family and different from those of other families. Ask students what characteristics are shared by their family members that are different from those of other people they know.

- Ask students which is more closely related evolutionarily to humans, bread mold, a maple tree, or a horse. How do they know this?

Activity Sequence

Day 1:

1. Preview the activity, its purpose, background, and learning outcomes

2. Procedure Part A: Develop a phylogenetic tree of common foods

3. Procedure Part B: Develop a phylogenetic tree of seven fish species

4. Procedure Part C : Run a gel electrophoresis procedure

Day 2:

5. Procedure Part D: Analyze gel banding patterns and develop a new fish phylogenetic tree

6. Follow-up discussion questions

Procedure

Day 1:

Part A: Phylogenetic Tree of Common Foods

1. Remind students that there are checkboxes in the Procedure sections of their handouts to track their progress in completing the lab.

2. Use common foods to teach how biological species can be organized according to their evolutionary relationship in a phylogenetic tree (this

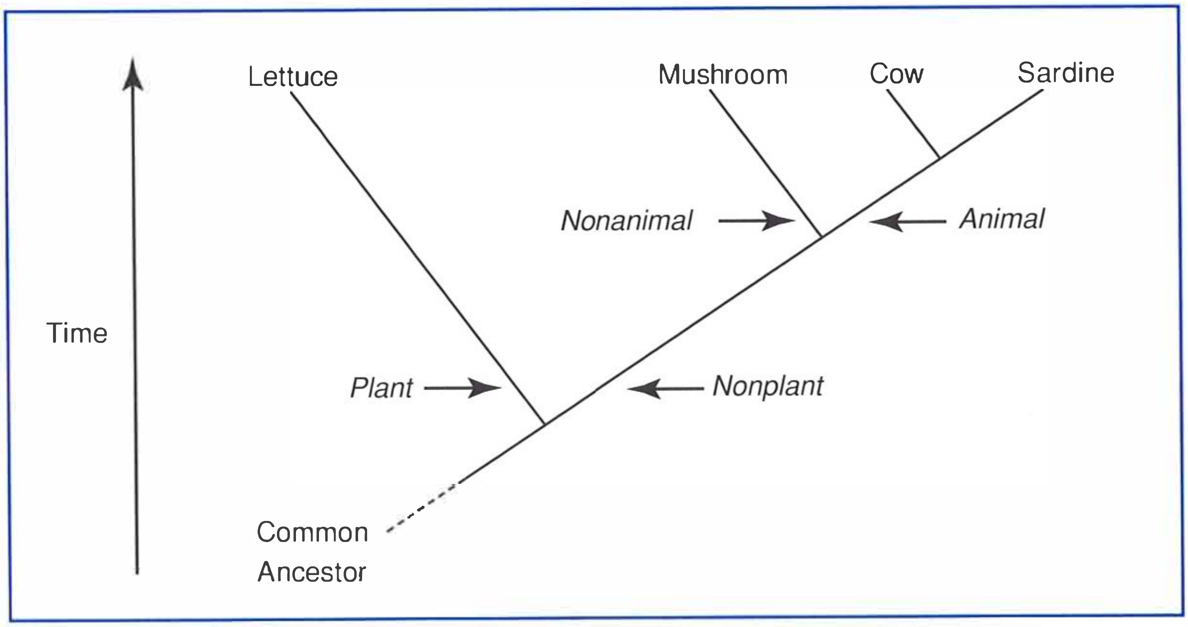


Figure 8.10. A phylogenetic tree of common foods

may be done in the lecture portion of the class before the day of the lab).

- Have students (alone or in groups of 2–3) place the following foods into a phylogenetic tree based on the closeness of their evolutionary relationship: lettuce, mushroom, cow (milk), and sardine.

- Emphasize to students that at each branch point in the tree, they should indicate a characteristic that differentiates one branch from another.

- The tree should look something like the one **in Figure 8.10**.

Part B: Fish Phylogenetic Tree Based on Habitat, Morphology, and Diet

Hypothesis Generation

1. Have students hypothesize a phylogenetic tree for the seven fish species that will be used in the lab, using pictures of the fish (available on the Web at www.landbigfish.com/fish/default.cfm) and the characteristics shown in the following table. Students should start drawing a tree by using only one characteristic. They will soon realize that there is often too much ambiguity when drawing a tree with so little information; encourage them to use multiple characteristics. More than one tree is possible, so there is no right answer.

2. Have students draw their phylogenetic trees on the board, and discuss why it is possible to draw different phylogenetic trees depending upon which characteristics are considered.

Fish species	**Characteristic**		
	Habitat	**Dorsal fin number**	**Diet**
Catfish	Freshwater river bottoms	2	Invertebrates, fish
Cod	Marine, medium depth	3	Herring, eel, shoal fish
Flounder	Marine, coastal bottoms	1	Mollusks, shrimp, fish
Halibut	Marine, deep ocean bottoms	1	Fish, large crustaceans
Perch	Freshwater lakes and ponds, medium depth	2	Larvae, fish eggs, small fish
Swordfish	Marine, medium depth	2	Different size fish, squid
Tuna	Marine, medium depth	2	Small fish, squid, shrimp,crab

Note: An alternative to presenting students with the table in this way is to pass out a table listing the fish and showing the characteristics headings, and then have students do research, either in class or for homework, to fill in the table. Profiles for these fish species are available on the Web at www.landbigfish.com/fish/default.cfm.

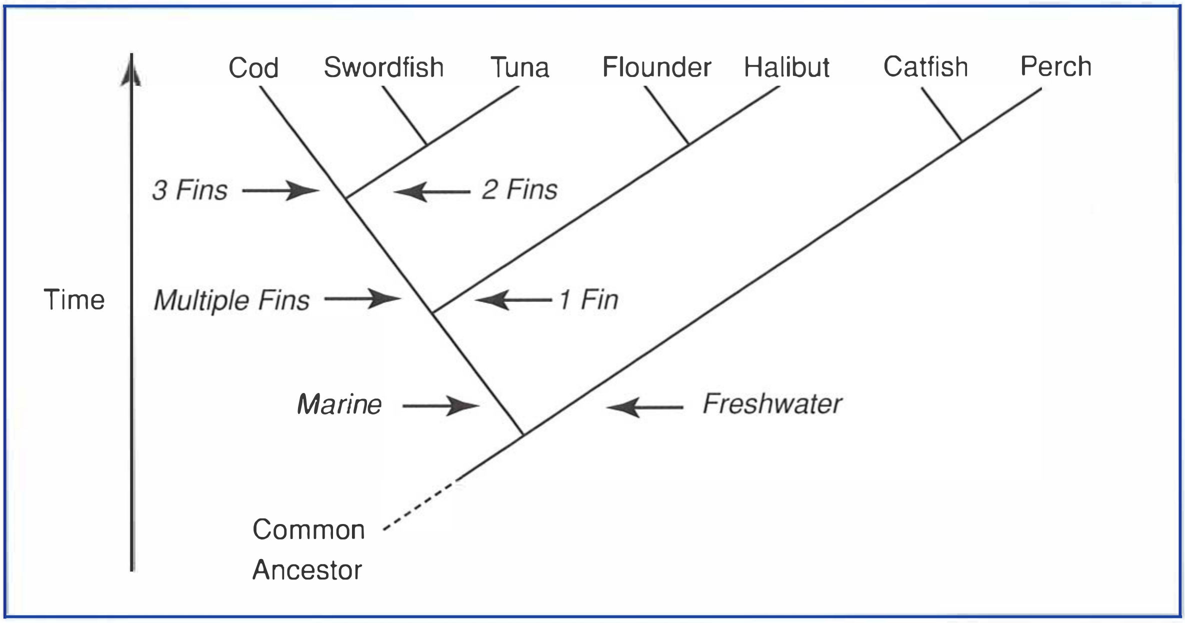


Figure 8.11. Phylogenetic tree of fish based on habitat, morphology, and diet

3. Figure 8.11 is an example of a phylogenetic tree that can be hypothesized based on these characteristics.

Part C: Gel Electrophoresis with Fish Proteins

Explanation of Gel Electrophoresis

1. Explain that the sizes of proteins in each fish species can be distinguished through gel electrophoresis in order to determine the species' degree of relatedness. The more related two species are, the more likely they will share proteins similar in size, because fewer mutations will have occurred since they diverged (according to the "molecular clock theory"). Conversely, if two species diverged from a common ancestor very long ago, relatively fewer proteins in these species would share a similar size. By comparing the pattern of protein bands on the gel, students will develop a very precise phylogenetic tree that can be compared to their hypothesized phylogenetic trees.

2. Demonstration: Introduce the concept of separating proteins in a gel on the basis of size by using the analogy of balls falling down a gently sloping pegboard. Ask students to predict which ball—a marble or a golf ball—will travel more quickly. Then drop the balls at the same time down the pegboard to confirm the result. Ask students why they think the smaller ball travels more quickly than the larger ball and reaches the bottom first (*answer: the smaller ball hits fewer pegs than the larger ball*).

3. Expand the pegboard analogy to explain how gel electrophoresis separates proteins on the basis of size. Protein samples are denatured (straightened) through the addition of sodium dodecyl sulfate (SDS) and β-mercaptoethanol. This also gives a negative charge to the proteins. After proteins are loaded into the gel and electrophoresis is performed, the proteins move away from the negative electrode

and toward the positive electrode. The rate of movement through the gel is dependent upon the length of the protein. Longer molecules interact with the gel meshwork more than shorter molecules, so longer molecules don't travel as far in the same amount of time.

Lab Protocol

Sample preparation

1. Put the screw-top tubes containing the fish protein samples and the protein size standard solution in a rack and place it in the boiling water bath for 3–5 minutes. DO NOT IMMERSE LIDS. (**See Figure 8.12**)

Protein separation by gel electrophoresis

1. Place the gel in the chamber with the wells on the black, or negative, side.

2. Cover the gel with electrophoresis buffer.

3. Load 10 µl of each sample and the size standard into the gel, one per lane (make note of the lane each solution is loaded into). One student should load one lane. It may be helpful to have the students practice pipetting with water beforehand. (**See Figure 8.13**)

4. Fasten the top of the electrophoresis chamber in place; be sure to keep the black and red sides together!

Figure 8.12. The protein samples immersed in a boiling water bath

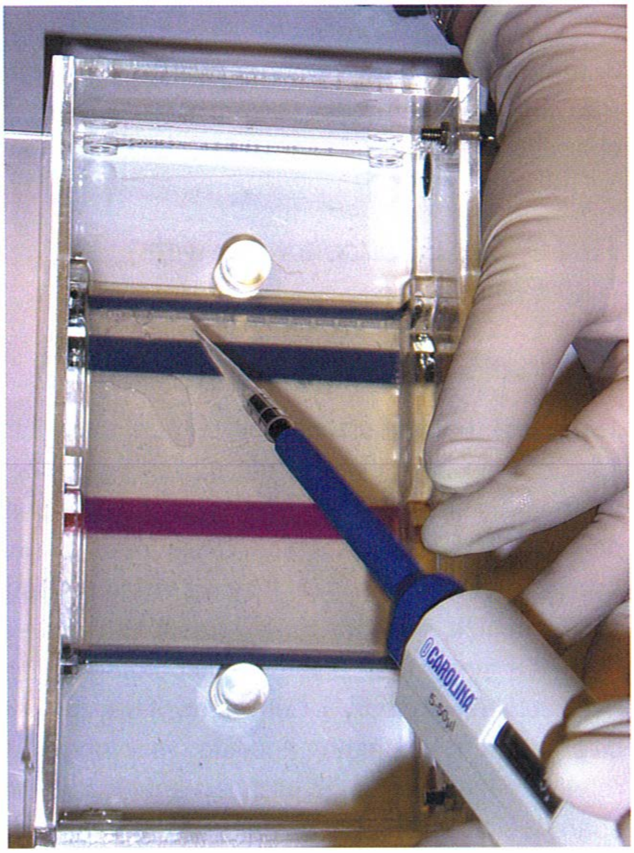


Figure 8.13. The protein samples being loaded into the gel of the casting tray

5. Attach electrodes to the power supply and run the gel at 100–135 volts.

6. The student portion of the lab can be stopped after completing steps a–d below, since 1–2 hours are needed for the electrophoresis to be completed. Before ending the lab, the instructor should:
  a. Review what students did.
  b. Describe how the gel will be developed.
  c. Preview how students will use the gel to complete the lab during the following class period (**see Part D**).
  d. Have students observe the initial movement of the bromophenol blue dye (a component of each protein solution) on the gel, so they can see the electrophoresis occurring.

Postlab follow-up and gel staining (does not have to involve students; use gloves)

1. After 1–2 hours, when the dye in the samples is close to the positive side of the gel, turn off the power supply and remove the gel from the chamber.

2. Transfer the gel to a staining tray.

3. Cover the gel with Coomassie stain for 10–20 minutes. Gently oscillate the tray every couple of minutes.

4. Remove the stain and cover the gel with Coomassie destain; leave overnight or until bands are visible (changing the destaining solution will speed the process).

Day 2:

Part D: Analyzing Gel Banding Patterns

1. During the next class period, the entire class can observe the gel if it is placed on a piece of plastic wrap and then on an overhead projector. The gel will not melt.

2. Have students draw a sketch of the gel and include the banding pattern for each fish species.

3. As a class activity, guide students in how to interpret the gel in order to determine the degree of relatedness between fish species.

4. Some useful strategies for interpreting gel banding patterns are as follows:

- Number the lanes 1, 2, 3, etc., and label the bands a, b, c, etc., in order to better organize group discussion of the gel.

- Initially, identify lanes with the most unique banding patterns. These would include, for example, the one with the fewest bands, the one with the most bands, or one with a pattern of bands that makes it stand out from the other lanes.

- Look at the number of bands that different lanes have in common. This can be made easier by redrawing the gel on a piece of scrap paper and cutting out the lanes so they can be moved next to each other for comparison.

5. Have students draw a phylogenetic tree that illustrates the evolutionary relationships shown from the banding patterns. A possible phylogenetic tree for the seven fish species appears **on page 265 in Figure 8.14**.

Follow-up Discussion Questions

Review:

1. What are the main concepts students have learned from this lab activity?
  Student responses will vary.

2. Why is a protein size standard solution included in this experiment?

The proteins in the protein size standard solution are of known sizes, so by comparing the fish bands to the protein size standard bands, one can get an idea of the size (in kilodaltons) of the fish proteins. Protein size standard solutions are traditionally included in gel electrophoresis.

3. Why was electricity used during the electrophoresis procedure?

Proteins are negatively charged. By running an electric current through the gel, the negatively charged proteins will move toward the positive charge. The gel itself sorts the proteins by size, so the smallest proteins will move the furthest through the gel to end up closest to the positive pole.

4. Why do scientists use phylogenetic trees?

Scientists use phylogenetic trees to communicate in graphic or visual form the known and/or hypothesized evolutionary relationships between specific groups of organisms.

Interpretive:

5. Does the gel banding pattern support only one type of phylogenetic tree, or are multiple trees possible based on the same data? Why?

Student responses will vary based on the banding pattern, but in general, multiple trees are possible. This shows that scientists put forward their hypothesis based on evidence, but that evidence is not always clear-cut and is open to interpretation.

6. Does the phylogenetic tree based on biochemical data correlate with the hypothesized tree based on habitat, morphology, and diet? Why or why not?

There should be some correlations here, but it is not meant to be perfect. Data and evidence based on anatomy, habitat, and diet are not as reliable as data from biochemical analysis.

7. If fish DNA instead of protein were used for gel electrophoresis,do you think the banding pattern and the phylogenetic tree based on it would be similar to or different from those in this experiment? Why?

They should be reasonably similar, because the DNA in the fish codes for the specific amino acids in the proteins.

Reflective:

8. Are there sources of error in this experiment? How might they have affected the results?

9. Did the lab help your understanding of how phylogenetic trees are developed?

10. What did you like or dislike about this lab?

11. How can this lab be improved to make it a better learning experience?

Formative Assessment

- Students will demonstrate their understanding of phylogenetic trees through the construction of their own phylogenetic trees in Procedure Part A and Part B, and through their participation during the follow-up discussion at the end of the activity.

- Students will demonstrate their abilities to load samples in a gel through their participation in Procedure Part C.

- Students will demonstrate their abilities to interpret electrophoretic banding patterns and decide if data supports a hypothesis during Procedure Part D and the follow-up discussion.

Summative Assessment

- Have students write up a report that includes background, the hypothesized phylogenetic trees, a description and figure of the phylogenetic tree based on protein banding patterns, and their conclusions. See the sample Lab Report Template **on page 163** as a guide.

- For further practice in analyzing gel banding patterns, the instructor could assign students to develop another phylogenetic tree using the handout Hypothetical Banding Pattern for a Protein Gel of Select Primates in Appendix C, "Student • Phylogenetic Trees 10."

Suggestions for Extended Learning

Give students the amino acid sequences for one protein (e.g., cytochrome c) from several species. Have students compare sequences, noting similarities and differences. Based on this comparison, have them develop a phylogenetic tree. This brings the focus of the lab to a more molecular level. Sequences and assignment are available on the Web at www.pbs.org/wgbh/evolution/educators/teachstuds/unit3.html.

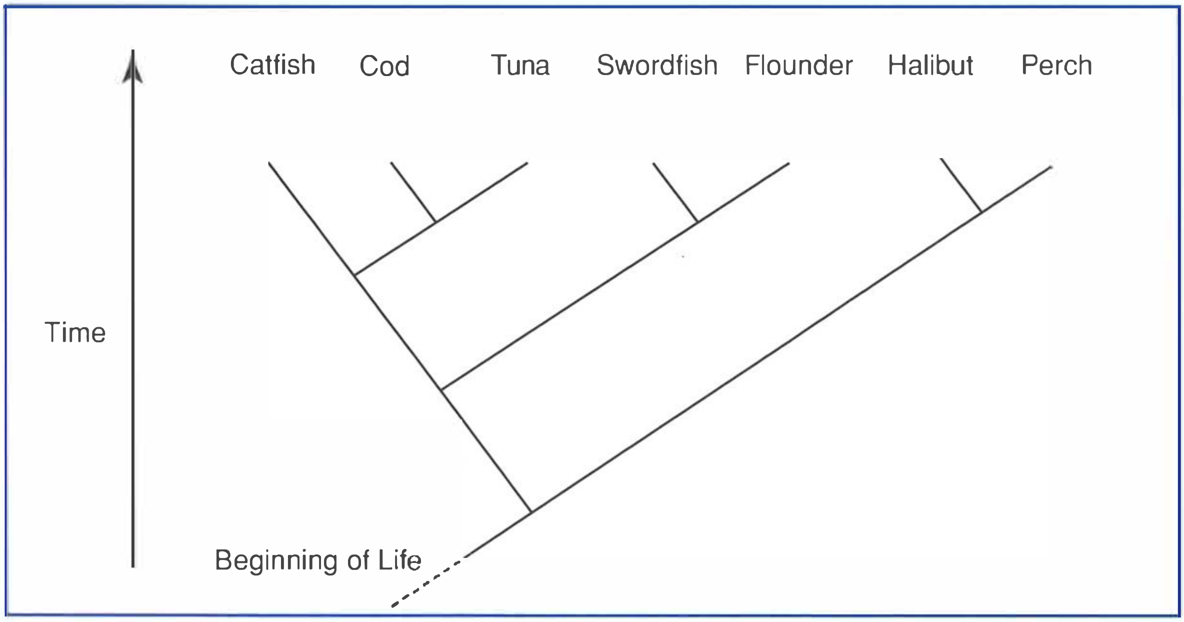


Figure 8.14. A possible phylogenetic tree of the bony fishes

Figure 8.14 is based on information from the following Web sites: http://tolweb.org/tree/phylogeny.html (*Tree of Life*) http://www2.biology.ualberta.ca/jackson.hp/IWR/ (*Ichthyology Web Resources*)

9 ACTIVITIES: CELL BIOLOGY

Introduction

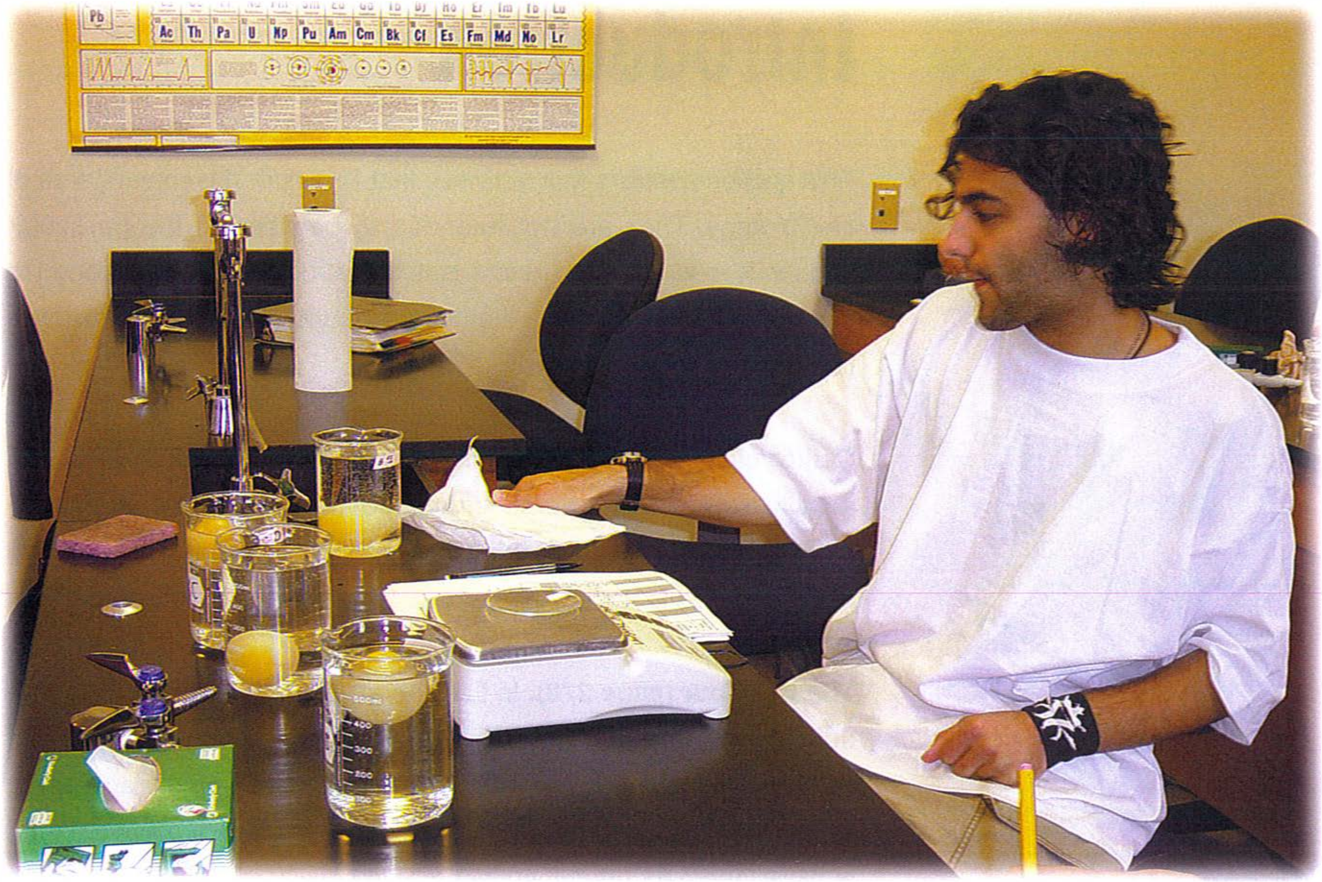
This section contains four activities that fall under the content area of cell biology. They are not intended to be used in the particular sequence in which they are presented. Instructors are encouraged to use them in any sequence that fits their curriculum. A short description of each activity follows.

Cell Cycle Role-Play (page 269). Students act out cell division. The activity is intended to demonstrate in detail an example of a kinesthetic-based learning technique. A supporting student handout to the activity can be found in Appendix C, "Student•Cell Cycle-Role Play."

The Cell Tour (page 278). In this interactive Web-based activity, students learn or review the basics of plant and animal cells as they take a virtual tour of a cell. This activity requires computer access for each student or student team. Student handouts are downloadable at www.landmark.edu/biosuccess. This activity is also contained on the CD found on the inside front cover of the book.

Environmental Factors and Enzyme Activity (page 281). Students test variables that may affect yeast enzyme activity. The activity is designed as a guided inquiry; the instructor supplies the investigative question and the materials, while the students design their own procedure and draw the subsequent conclusions. A complete student handout is provided in Appendix C, "Student • Environmental Factors and Enzyme Activity."

Egg Osmosis (page 286). In this lab-based activity, students use eggs to chart osmotic rates in different solutions. There are three versions of this activity: demonstration, structured inquiry, and guided inquiry. Each version is based on the level of structure and guidance provided to students as they carry out the activity. A complete student handout for each version appears in Appendix C, "Student • Egg Osmosis."



Cell Cycle Role-Play

Time Required: 60 minutes

Summary

The instructor leads students through a kinesthetic role-play to teach the cell cycle. **See page 81** for background on using multimodal teaching techniques. Students act out the behavior of chromosomes and centrioles and use props to represent other components of this process. This activity would take place at the end of a cell biology unit, when students are familiar with the basics of cell structure. As presented here, the activity works best as a technique to introduce the cell cycle, but it could easily be adapted to reinforce or review this process. A short video clip showing the activity is included on the CD found on the inside front cover of this manual.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Define the purpose of cell division
- List the following stages of the cell cycle in their correct sequence: G_1 phase, S-phase, G_2 phase, interphase, prophase, metaphase, anaphase, telophase, and cytokinesis
- Identify the major cellular events associated with each of the stages just listed
- Associate key organelles and structures involved in cell division with their functions
- Differentiate between a chromosome and a chromatid

National Science Education Standards: Content Standards C:1:1 and C:1:6 (see Appendix B)

Materials

(a prop's analogous cellular component appears in parentheses)

- 2 heavy-duty extension cords, each 20 feet long, of the same color (cell membrane)
- 8 pieces of twine, cut into approximately 10-foot lengths; two pieces for each of four chromosomes (spindle fibers)
- 10-foot length of ribbon or flagging tape (metaphase plate)
- 2 bedsheets, blankets, or tarps, each large enough when laid out for eight students to stand on (nuclear membrane)
- Labels for props:
  - — 2 pieces each of blue, green, yellow, and red paper (for chromosomes)
  - — 14 pieces of white paper (for other cell cycle components)
- Poster, plaque, or free-standing model of the cell cycle
- Beaker filled with baking soda
- Vinegar
- Magic markers
- Tape

Figure 9.1. Cell Cycle Role-Play materials: (*left to right*) colored paper for chromosome/chromatid labels, blue flagging tape, 8 pieces of green twine, 2 extension cords, 2 tarps

Instructor Preparation

- Space requirements: A room large enough to accommodate a 15-foot-diameter circle (as well as additional space for an audience, if present) should be adequate.
- Ten students are required to be players in the role-play procedure, which is based on 4 chromosomes (2n = 4).

  — Two students are needed to play the role of each chromosome (8 students total). The instructor may modify the number of chromosomes based on class size, space demands, etc. If this is done, the number of players and amount of materials will also have to be modified.

  — Two students are needed to play the role of centrioles.
- If the class size is too large to accommodate all students acting as players concurrently, the role-play can be performed by one set of students while the rest act as an audience, and

then the roles of players and audience can be reversed. Ideally, the audience should stand on tables or in a balcony to get a bird's-eye view of the role-play.

- Prepare a poster of each stage of the cell cycle, or have available a commercial poster, plaque, or free-standing model to refer to as the activity proceeds.

- Copy the student handout (**see Appendix C,** "Student•Cell Cycle Role-Play"), one for each student.

- Write the following "playbill" for the role-play on the board or a poster, so that each act or scene can be checked off as the activity proceeds.

  Act 1: Prelude
    Scene 1 — A Day in the Life
    Scene 2 — Copycats I
    Scene 3 — Copycats II
  Act 2: Sorting Out the Pieces
    Scene 1 — Getting Some Breathing Room
    Scene 2 — Line Dancing
    Scene 3 — Homeward Bound
    Scene 4 — There's No Place Like Home
  Act 3: Finale
    Scene 1 — Coming Apart at the Seams

- Prelabel the paper for the players:

  Colored paper
  — These are labels for chromosomes/chromatids. The instructor may want to cut the paper into the shape of contracted chromosomes to help students make a connection with how chromosomes are drawn in their textbook.

  — On each blue piece, write "blue sister chromatid" on one side and "blue chromosome" on the other side.

  — Repeat for each remaining color of paper.

  White paper
  — Write "centriole" on two pieces of white paper.

- Prelabel the paper for the props:
  Write each of the following terms on the number of pieces of white paper indicated in parentheses:
  — *centromere* (4)
  — *cleavage furrow* (1)
  — *metaphase plate* (1)
  — *spindle fiber* (2)

- Keep four pieces of white paper blank.

- If any additional vocabulary words are introduced, visual references need to be made for them as well.

Activator/Connector

- Probe students' knowledge of human development and repair mechanisms. Humans start out as single-celled zygotes and develop into multicelled organisms. After an injury, damaged tissue is replaced by new tissue. How does one cell turn into many?

- In small groups, have students list the basic parts of an animal cell. Call on each group until a complete list is on the board. Then ask them the following question: *If you were an animal cell and needed to divide to make two identical new cells, which parts would you need to incorporate into each new cell in a precise manner to ensure survival?* Lead the discussion toward the conclusion that primarily DNA must be partitioned into each new cell in a nonrandom manner. Random partitioning of other cell parts is tolerated because their numbers can be adjusted to normal levels based on information contained in the DNA.

Activity Sequence

1. Preview the activity, its learning outcomes, and the rationale for doing it kinesthetically

2. Role-Play A: Walk-through with players labeled by role; clarification as necessary

3. Role-Play B: Walk-through with players and props labeled; clarification as necessary

4. Role-Play C: Student narration and role switching

5. Follow-up discussion questions

Procedure

Role-Play A:

Role-Play A is a walk-through activity. Use terms for *parts of the cell* that students are already familiar with and label only the players involved. These terms appear in bold below. It is recommended that terms associated with the *stages of the cell cycle* (e.g., metaphase plate) not be introduced until Role-Play B. These terms are included in directions for Role-Play A for the instructor's benefit only. Emphasize that this activity models the cell cycle in animal cells, which differs slightly from that in plant cells.

Note: Steps 1–3 could take place before the class assembles to save class time.

1. Connect two extension cords (**cell membrane**) at both ends and lay them out to form a large circle (the **cell**). The connected ends should be situated midway between the poles of the cell as designated by the instructor.

2. Lay out the sheet (**nuclear membrane**) on the ground somewhere within the cell.

3. Lay out the ribbon (**metaphase plate**) along the plane midway between the cell poles, and attach it to the floor with tape.

4. Divide students participating in the role-play into five pairs, four to represent **chromosomes** and one to represent **centrioles**.

Chromosome pairs:
a. Each pair should choose a unique color label.
b. One member of each pair should attach both labels of their chosen color (one on top of the other) to himself or herself, with the word "chromosome" facing outward, and stand on the sheet in a random location.
c. The other member of each pair should remain outside the cell.

Centriole pair:
a. One member of the pair should attach both pieces of white paper labeled "centriole" (one on top of the other) to himself or herself, and then stand outside the nucleus but inside the cell.
b. The other member should remain outside the cell.

5. Have students make a mental note of the initial configuration (colors and number) of chromosomes in the cell.

6. Act 1: Prelude (Interphase)

Scene 1: A Day in the Life (G_1 phase)

Explain to students that initially the cell carries out general metabolic activity. To illustrate this, place the beaker with baking soda in the cell and pour vinegar into it to indicate that a chemical reaction is occurring (additional props to demonstrate metabolic activity could include a remote control car driving around to indicate diffusion, or a hot air popcorn popper making popcorn to indicate protein synthesis).

Scene 2: Copycats I (S-phase)

Simulate DNA replication by having each of the four chromosomes on the outside of the cell join their partners in the nucleus, standing side-by-side and locking elbows. The member of the chromosome pair originally in the nucleus gives one of his or her colored labels to the partner, and they both attach them with the words "sister chromatid" facing outward. Explain that the term "chromatid" is the new name for "chromosome" after DNA replication occurs (discuss the reasoning for this later). **(See Figure 9.2)**

Scene 3: Copycats II (G_2 phase)

Simulate centriole replication by having the other member of the centriole pair walk into the cell and stand alone. The original member attaches one of the papers labeled "centriole" to the new member, who remains outside the nucleus.

Figure 9.2. Sister chromatids face outward

Figure 9.3. Spindle fibers extend from the centromere to each sister chromatid pair

Figure 9.4. The ends of the extension cords are brought together to simulate cytokinesis

7. Act 2: Sorting Out the Pieces (Mitosis)

Scene 1: Getting Some Breathing Room (Prophase)

a. At the start of mitosis, the instructor removes the sheet to simulate disappearance of the nuclear membrane. Sister chromatid pairs should remain attached and walk randomly off the sheet, but remain within the cell.
b. Centrioles should walk to opposite sides of the cell, near the middle of each extension cord.

Scene 2: Line Dancing (Metaphase)

a. Give one end of a piece of twine to a centriole and place the other end in the hand of one member of a sister chromatid pair. Repeat this process until twine extends from the centriole to each sister chromatid pair. This simulates attachment of spindle fibers at the centromere.
b. Repeat for the other centriole, except give the free end of twine to the member of each sister chromatid pair that did not previously receive twine.
c. Sister chromatid pairs now move toward the center of the circle and stand along the ribbon, facing perpendicular to the centrioles. (**See Figure 9.3**)

Scene 3: Homeward Bound (Anaphase)

a. Sister chromatids disjoin by unlinking elbows. Then they should turn over the "chromatid" label so the term "chromosome" is facing outward.
b. The centrioles begin to reel in the twine, causing newly disjoined chromosomes to move to the poles of the cell.

Scene 4: There's No Place Like Home (Telophase)

Place a sheet at each pole and have the group of chromosomes nearest the sheet stand on it. The centrioles should remain off the sheet. This represents reappearance of nuclear membranes around the chromosomes.

8. Act 3: Finale

Scene 1: Coming Apart at the Seams (Cytokinesis)

Move the connected ends of the extension cords toward each other until they meet in the middle of the cell. Unplug and reattach them to form two separate circles, which represent the two daughter cells. This simulates cytokinesis. (**See Figure 9.4**)

9. Take some time to address any questions that arise with students needing clarification.

10. Explain the difference between *chromosome* and *chromatid* at this point, or have a student(s) try to do so.

Role-Play B

1. The entire sequence of events should be walked through a second time. It is preferable to use the same volunteers, since they are familiar with their specific roles, and for the instructor to continue being the director. Tell students that at the end of this and subsequent walk-throughs, one or several students will be randomly picked to narrate the next walk-through. This will encourage students to pay attention, since they may be called on.

2. Introduce terms for the stages of the cell cycle that correspond to each act and scene as they occur during the role-play. For each stage introduced, refer to the poster of the cell cycle that is displayed.

3. Introduce the biological name represented by each prop (*centromere, spindle fibers, metaphase plate, cleavage furrow*) as it appears in the

role-play and use a visual reference to reinforce the term. For example, after DNA replication, label the centromere, represented by the locked elbows of sister chromatids, by taping the piece of paper labeled "centromere" over the elbows. Attach the paper labeled "spindle fiber" to one piece of twine on each side of the cell so the term is visible from both sides of the room, and so on.

4. Take time to address any additional questions that arise with students needing clarification.

Role-Play C

1. We recommend allowing a student to take on the narrator/director role and explain the process. This may be a student who has not yet been directly involved or one who has taken on a role. Audience members and active role-players also have the opportunity to switch roles at this point. This increases the investment of students in the audience and allows the original actors to witness the role-play from a new perspective.

2. Repeat as necessary, with different students taking the narrator/director and other roles.

Follow-up Discussion Questions

Review:

1. What biological stages and what cellular events take place in each of the acts and scenes?

See Role-Play A procedure beginning on page 272.

2. How do the daughter cells compare to each other and to the original cell in terms of the number and identity (colors) of their chromosomes?

They are the same.

3. What mechanism or mechanisms ensure that chromosomes similar in quantity and identity are partitioned into each daughter cell?

The attachment of sister chromatids at the centromere until anaphase assures that when the chromosomes separate, one of each kind goes to each new cell.

4. How do chromosomes differ from chromatids?

A chromosome is a single long strand of DNA supercoiled into a tight "package." A chromatid is one of a pair of replicated chromosomes—exact copies of each other—which are connected at the centromere.

Interpretive:

5. How would the role-play need to be modified to represent the cell cycle in plant cells?

Plant cells have asters rather than centromeres, but they perform the same role, so only the signs would need to be changed. Plant cells have a cell wall, so something to represent the cell wall would need to be added, in a form that could demonstrate the formation of a new wall between the two daughter cells after cytokinesis.

6. If a mistake occurred during mitosis and the spindle fibers failed to attach to the chromosomes, what do you think would be the consequence in terms of the number of cells formed and the number of chromosomes in each cell after cytokinesis took place?

If the spindle fibers did not attach at all, there would be no movement of the chromosomes at all. Presumably, there would be no cytokinesis, as none of the steps of mitosis would occur. The cell would now have four copies of each chromosome rather than two, but they would still be attached as sister chromatids. If cytokinesis did occur, the chromosomes—still as sister chromatids—would divide randomly into the two new cells, with each new *cell having two copies of some chromosomes (as sister chromatids), four copies of some, and no copies of others.*

Reflective:

1. Which part of the model is still unclear to students?

2. Did students find the role-play to be an effective learning instrument? How could it be improved as an activity?

3. Does the kinesthetic approach complement individual learning styles of students in the class?

4. Do students have other ideas on how best to learn this material?

Formative Assessment

Students will demonstrate their understanding of all learning outcomes through their active participation in the role-play scenarios, their ability to ask clarifying questions during the role-play, and their oral and written participation during the follow-up discussion component of the activity.

Summative Assessment

- Assign students to write a summary of cell division using the Writing Model for a Biological Process **on page 115**.

- Students should fill in the rest of their "playbill" student handout. Have them:
  — Write the name of each stage of the cell cycle next to the act or scene it appears in
  — Make a drawing of each stage as it appears in a textbook
  — In their own words, write a description of events that take place in each stage

Suggestions for Extended Learning

Assign students to develop a role-play for meiosis, using similar props and adapting them as necessary.

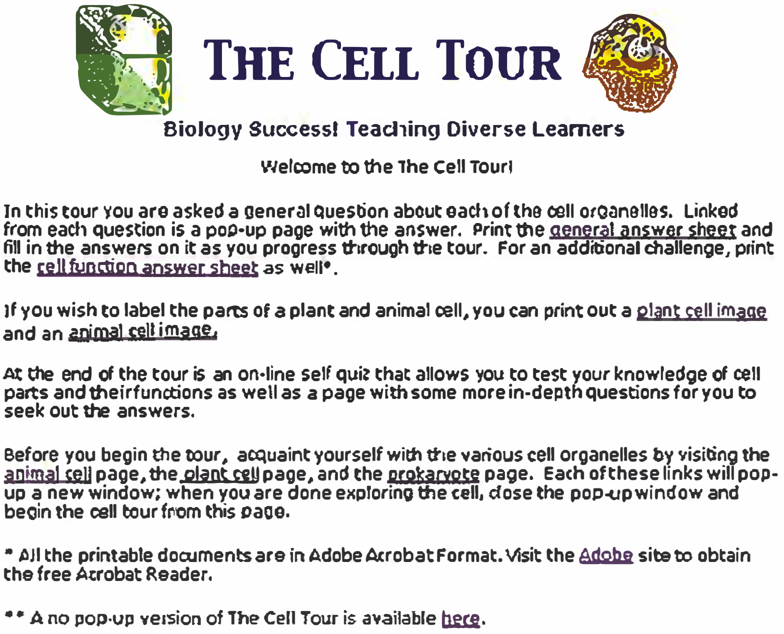
The Cell Tour

Time Required: 1–1½ hours

Summary

The Cell Tour is an interactive Web-based activity, best employed as a review of basic eukaryotic cell structures, functions, and organelles. Every description of the structure and function of a cell organelle is followed by a question that encourages students to explore the topic further and/or to make connections with previously learned material. Answers to these questions can be immediately obtained by following a link to a page with additional information about that organelle. Students can print out a sheet listing all of these questions so they can record and track their answers. In addition, students can print out a form that lists the organelles included in the tour and provides a space for writing the corresponding function(s). This form could later serve as a review guide.

If students are proficient with computer use, The Cell Tour may be assigned as homework that reviews and expands their knowledge of the cell parts. Computer skills needed to complete the tour are proficiency using a Web browser, such as Internet Explorer, and the ability to download and, if necessary, install the software Adobe Acrobat Reader (Acrobat Reader comes preinstalled with most computers). If students are uncomfortable with these skills, The Cell Tour should be run during class time. The Cell Tour can be found at www.landmark.edu/biosuccess and on the CD included with this book.



THE CELL TOUR

Biology Success! Teaching Diverse Learners

Welcome to the The Cell Tour!

In this tour you are asked a general question about each of the cell organelles. Linked from each question is a pop-up page with the answer. Print the general answer sheet and fill in the answers on it as you progress through the tour. For an additional challenge, print the cell function answer sheet as well*.

If you wish to label the parts of a plant and animal cell, you can print out a plant cell image and an animal cell image.

At the end of the tour is an on-line self quiz that allows you to test your knowledge of cell parts and their functions as well as a page with some more in-depth questions for you to seek out the answers.

Before you begin the tour, acquaint yourself with the various cell organelles by visiting the animal cell page, the plant cell page, and the prokaryote page. Each of these links will pop-up a new window; when you are done exploring the cell, close the pop-up window and begin the cell tour from this page.

* All the printable documents are in Adobe Acrobat Format. Visit the Adobe site to obtain the free Acrobat Reader.

** A no pop-up version of The Cell Tour is available here.

Figure 9.5. The Cell Tour Web site

Learning Outcomes

After completing this activity, students will be able to:

Content

- Associate cell organelles and structures with their functions
- Identify those organelles/structures common to both animal and plant cells, as well as those that are unique to each cell type

Computer Skills

- Use a Web browser
- Download and install Adobe Acrobat Reader
- Print pages from a Web-based activity

National Science Education Standards:

Content Standard C:1:1 (see Appendix B)

Materials

Computer equipped with

- CD-ROM drive or Internet connection
- Internet browser, such as Internet Explorer
- Printer

Instructor Preparation

Before introducing The Cell Tour to students, instructors should be comfortable with using a computer and an Internet browser. The Cell Tour is meant to serve as a review of eukaryotic cell structures, to be completed after students have already been introduced to them. It is recommended that the instructor print out an unlabeled cell diagram (plant cell and animal cell images are linked to the first page of the tour) so that students can add labels as they progress through the tour.

Activator/Connector

Tell students that "organelle" means "little organ." Ask students to describe the basic functions of a few well-known organs of the human body (heart, liver, etc.). Then make the analogy between a cell and a whole organism, like the human, and between organelles and organs. A human has a liver which detoxifies harmful chemicals; does a cell have a comparable organelle that is involved in detoxification? Humans have a bony skeleton which provides internal structural support. Do cells have an internal support structure?

Activity Sequence

1. Preview the activity and its learning outcomes

2. Guide students to The Cell Tour home page

3. Have students print out the following forms as needed:
   - List of all organelles included on The Cell Tour, with blanks provided for writing in corresponding functions
   - Animal and plant cell diagrams for labeling
   - List of questions asked during The Cell Tour, with spaces for writing answers

4. Have students complete The Cell Tour and any assigned forms (answers to questions are found within The Cell Tour itself)

5. Ask students to take the interactive self-quiz and review cell organelles as needed

Procedure

Use of The Cell Tour is self-explanatory beginning on the first page.

Follow-up Discussion Questions

Review:

1. Ask students to complete the self-quiz following completion of The Cell Tour.

Interpretive:

2. Ask students to complete the questions that appear at the end of The Cell Tour.

3. Ask students to think of the cell as a factory and assign roles to certain organelles. For example, *if the cell were a factory, the mitochondria would be the boilers and the lysosomes would be the janitors*.

Reflective:

4. Ask students to reflect upon the best way to learn about cell organelles and their functions.

5. Ask students whether a visual, self-paced tour of the cell aided their learning.

Formative Assessment

- Students will demonstrate their ability to associate cell structures with their functions, and to identify those organelles and structures common to both animal and plant cells and those that are unique to each cell type, during their work using The Cell Tour and taking the follow-up self-quiz.

- Students will demonstrate their abilities to use a Web browser, download and install Adobe Acrobat Reader (if necessary), and print pages from a Web-based activity as they carry out The Cell Tour on a computer.

Summative Assessment

- Ask students to construct a three-dimensional model of a plant or animal cell.
- Give students a short quiz based on the learning outcomes.
- Ask students to complete a concept map on cell structure and function.

Suggestions for Extended Learning

Have students compare and contrast this Cell Tour with other online cell Web sites, such as

- The Virtual Cell Tour, http://personal.tmlp.com/Jimr57/
- Eukaryotic Cell Home Page, http://www-class.unl.edu/bios201a/spring97/group6/

Environmental Factors and Enzyme Activity

Time Required: 2 hours

Summary

Students observe a teacher demonstration of yeast reacting with peroxide to produce oxygen gas. They are then asked to choose a variable that may influence the rate that gas is produced (e.g., temperature, pH, etc.), and develop and test a hypothesis in order to understand what factor(s) influence enzyme activity.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Describe the functions of enzymes as catalysts
- Identify variables that affect enzyme activity

Inquiry Skills

- Formulate testable hypotheses
- Design experiments to test hypotheses
- Display data in both tabular and graphic form
- Calculate averages
- Decide whether data support hypotheses

Communication Skills

- Write a scientific lab report which accurately summarizes the experiment

National Science Education Standards:

Content Standards A:1:1, A:1:2, A:1:3, A:1:4, A:1:6, A:2, and C:1:2 (see Appendix B)

Materials

- 3% peroxide solution
- Dry, granulated yeast
- Felt cut into 2cm x 2cm squares
- Ice
- Dilute HCl (0.1 M)
- Dilute NaOH (0.1 M)
- pH paper or meter
- Stopwatch

Instructor Preparation

This lab would be most useful after the structure and function of enzymes have been introduced. Also, a review of the scientific method would be helpful, including making observations and hypotheses, understanding dependent vs. independent variables, the need for replication, etc.

Activator/Connector

Ask students questions about a chemical reaction involving yeast that is familiar to them:

- Have you ever made bread? What allows it to rise?

- Where do the bubbles in beer or champagne come from?

Activity Sequence

1. Preview the activity, its purpose, general background, and learning outcomes

2. Teacher demonstration of enzyme reaction (Procedure Part A)

3. Discussion of reaction and possible variables affecting reaction (Procedure Part B)

4. Student generation of hypotheses and experimental procedures (Procedure Part C)

5. Data analysis and presentation (Procedure Part D)

6. Follow-up discussion questions

Procedure

Part A: Teacher Demonstration

Remind students that there are checkboxes in the Procedure sections of their handouts to track their progress in completing the lab.

1. Dissolve 10–15 grains of yeast in 300 ml H_2O. (*Note*: Yeast may vary in viability. It's advisable to test your solution prior to use.)

2. Dilute 10 ml of 3% peroxide solution in 90 ml H_2O (100 ml total).

3. Using forceps, dip the felt square into the yeast solution until it's saturated.

4. Drop the yeast-saturated felt square into the diluted peroxide solution (it may take as long as 30 seconds to sink).

5. Record the total amount of time the felt takes to sink and rise back to the surface (this can range from 1 to 2 minutes).

6. As a control, dip the felt square into a 100% water solution and then drop it into the peroxide solution.

7. Record the result of the control and compare it to the behavior of the yeast-saturated felt square (the water-soaked felt square will not rise, indicating that no chemical reaction has occurred and that the enzyme is in the yeast).

Part B: Teacher-Led Discussion

1. Write the chemical equation for the reaction on the board and identify the reactants, products, and enzyme involved. Specify to the students that catalase is a chemical *within* yeast; yeast itself is not the enzyme.

$$H_2O_2 \text{ (peroxide)} \xrightarrow{\text{catalase}} H_2O + \tfrac{1}{2}O_2 \text{ (g)}$$

2. Ask students why the felt initially sinks to the bottom of the beaker and later rises to the surface.

The yeast solution makes the felt initially heavier than the peroxide solution; the reaction then produces oxygen gas in the felt, making it buoyant.

3. Ask students what variables might affect the time it takes for the felt to sink and then rise again (e.g., concentration of yeast or peroxide solutions, temperature or pH of the peroxide solution, etc.) and what treatment levels for these variables could be investigated:

Variable to be investigated:	Suggestions for treatment levels:
1. Yeast solution concentration	Concentrations should differ by an order of 10
2. H_2O_2 solution concentration	Concentrations should differ by an order of 10
3. H_2O_2 solution temperature	Place yeast and peroxide solutions in ice cold water, room temperature water, and warm tap water baths
4. H_2O_2 solution pH	pH 3, 7, and 10 (students can adjust the pH using dilute HCl and NaOH and test the pH using pH paper or a pH meter)

Part C: Student-Generated Hypothesis Testing and Experimentation

1. Assign students to groups of 2–3

2. Have each group perform the following:
   - Choose a variable
   - Develop a hypothesis of how that variable might affect the reaction time
   - Develop and carry out a procedure to test the hypothesis (remind students that a minimum of three replications is necessary to calculate a valid average)
   - Predict the outcome of their self-generated procedure

Part D: Data Analysis and Interpretation

1. Have students use the following sample table to make a data table specific to their variable for recording results (or, if appropriate, ask students to make their own table).

Level of variable	Time needed for felt to sink and rise to surface (seconds)			
	Trial 1	Trial 2	Trial 3	Average

2. Ask students to calculate averages and graph them (e.g., level of variable vs. time to sink and rise), or show them how using an example.

3. Have students compare averages and develop an explanation of why their hypothesis was or was not supported.

4. When all students have finished their experiments, have each group share with the class their hypothesis, prediction, experimental procedure, and results.

Follow-up Discussion Questions

Review:

1. What are the main concepts students have learned from this lab activity?

2. What is the general role of enzymes for all organisms?

Enzymes in organisms act to speed and facilitate metabolic reactions that might otherwise be very slow or nonexistent.

3. Based on the class data, what variables affect enzyme reaction rates and in what way?

- *Increasing the yeast concentration should increase the rate. This is equivalent to increasing the enzyme concentration. The rate should go up with enzyme concentration, unless the substrate concentration is very low.*

- *Increasing the* H_2O_2 *concentration should increase the rate; decreasing it should decrease the rate. The rate will level off with increased concentration when the substrate concentration is high enough to saturate the enzyme.*

- *Increasing the temperature should increase the rate, up to a point. If the temperature gets too high, the enzyme will stop working. Decreasing the temperature should decrease the rate.*

- *Changing the pH too far in either direction should reduce the rate. Enzymes have ideal pH levels at which they work.*

Interpretive:

4. If other levels of the variable were used, what results might be predicted for the experiment?

Student responses will vary, but the idea is that the treatment levels chosen for the independent variable have an important role in how the experiment plays out. Identifying the treatment level that has the most pronounced effect can take several rounds of experimentation.

Reflective:

5. Are there sources of error in this experiment? How might they have affected the results?

6. What aspects of the activity most contributed to students' understanding or were most challenging? How might this understanding be applied to the next lab experiment run?

7. How could the lab be improved?

Formative Assessment

- Students will demonstrate their abilities to describe the function of enzymes through their participation in the follow-up discussion to the activity.

- Students will demonstrate their abilities to develop a hypothesis, choose a variable, and perform an experimental procedure during Procedure Part C of the lab.

- Students will demonstrate their understanding of the effects of environmental conditions on enzyme activity through their active participation in running their experiments and sharing their findings and conclusions orally in the follow-up discussion section of the lab.

- Students will demonstrate their skills with constructing data tables and calculating averages, as well as deciding whether data supports a hypothesis, during Procedure Part D of the lab, and during the discussion component of the lab when they present their findings.

Summative Assessment

Ask students to use the Lab Report Template **on page 163** to summarize the experiment in writing. In addition, supply an assessment rubric, such as the one found **on page 130**. Students should present their data in both tabular and graphic forms.

Suggestions for Extended Learning

- Ask students to research why factors such as temperature or pH can affect enzyme activity. Ask them to bring this information to the next class session for presentation.

- Ask students to devise an additional hypothesis and experimental design related to enzyme activity.

Egg Osmosis

Special Introduction: This lab activity provides a model for how instructors can convert demonstration laboratory exercises into structured inquiry and guided inquiry versions. **See page 158** for an explanation of the inquiry continuum. The demonstration version of this lab has students follow a set of instructions to a predetermined outcome in order to demonstrate the concept of osmosis. The inquiry-based labs allow for more student participation with respect to developing alternative procedures or experiments to study this concept. Based on student ability, the instructor has the choice of conducting the demonstration lab first to allow students the opportunity to practice the basic procedures they'll need for completing one of the inquiry-based osmosis labs at a later date. Alternatively, the demonstration version could be skipped altogether, and students can complete one of the inquiry-based labs.

OSMOSIS LAB: DEMONSTRATION VERSION

Time Required: 2–2½ hours

Summary

The Demonstration version of this lab has students follow a set of instructions to a predetermined outcome in order to demonstrate the concept of osmosis. Deshelled eggs are submerged in hypotonic, isotonic, and hypertonic sugar solutions, and changes in their weights are recorded.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Define the process of osmosis
- Differentiate among the terms *hypertonic*, *hypotonic*, and *isotonic*
- Identify variables that affect osmosis (Guided Inquiry only)

Inquiry Skills

- Formulate testable hypotheses (Guided Inquiry only)
- Design experiment to test hypotheses (Guided Inquiry only)
- Display data in both tabular and graphic form
- Calculate averages

- Decide whether data support hypotheses (Guided Inquiry only)

Lab Skills

- Make percent (by volume) solutions (Structured Inquiry and Guided Inquiry only)
- Use weighing balance

Communication Skills

- Write a scientific lab report which accurately summarizes the experiment

National Science Education Standards: Content Standards A:1:1, A:1:2, A:1:3, A:1:4, A:1:5, A:1:6, A:2, and C:1:1 (see Appendix B)

Materials

Each lab team should have the following:

- Four raw eggs (presoaked in vinegar to remove the shell)
- Various percent solutions of clear corn syrup **(see Instructor Preparation)**
- Balance
- Paper towels
- Spoon
- Timer
- Graph paper

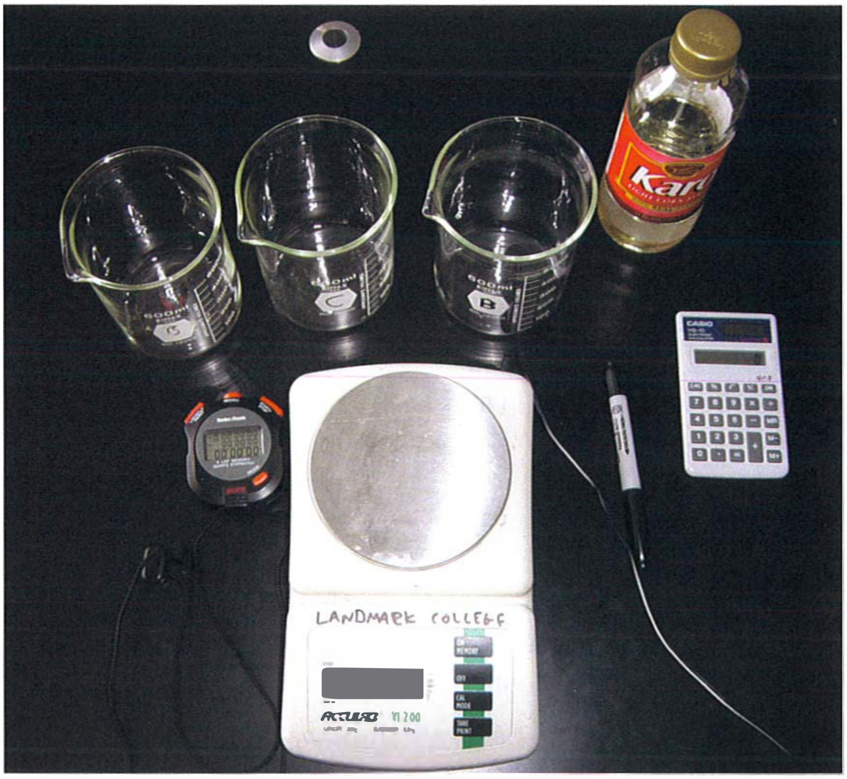


Figure 9.6. Materials: (*clockwise*) beakers, Karo corn syrup, calculator, electronic balance, stop watch

Instructor Preparation

- Presoak eggs in vinegar for 48 hours to remove the shell.

  1. White eggs are better to use than brown eggs, as their shells come off more easily.
  2. For best results, soak eggs for 24 hours, drain the vinegar, add fresh vinegar, and soak for another 24 hours.
  3. Remove any remaining shell by rubbing eggs gently under running water.
  4. Prepare four eggs per lab team, as well as several extra in case of breakage.

- For each lab team, prepare four solutions differing in solute concentration. Use 600-ml beakers labeled A, B, C, and D. The solutions should be prepared in the following manner:

  A: 0% solution — 500 ml water only
  B: 5% solution — add 25 ml clear corn syrup to 475 ml water
  C: 30% solution — add 150 ml clear corn syrup to 350 ml water
  D: 50% solution — add 250 ml clear corn syrup to 250 ml water

- This lab would typically occur after the concept of osmosis and the terms *hypertonic*, *hypotonic*, and *isotonic* have been introduced in the lecture portion of the class.

Activator/Connector

- Ask students whether they have ever used salt to draw out water (and some bitter-tasting solutes) from eggplant slices?

- Ask students whether they have ever prepared fruit salad. Ask if they've noticed that adding sugar to the cut pieces of fruit increases the volume of juice that forms.

Activity Sequence

1. Preview the activity, its purpose, background, and learning outcomes

2. Procedure: Measuring weight changes in the eggs

3. Data display and analysis

4. Follow-up discussion questions

Procedure

Lab Preview

- Assign students to groups of 2–4.

- Remind students that there are checkboxes in the Procedure sections of their handouts to track their progress in completing the lab.

- Review the entire lab procedure with students before beginning the lab.

- Explain how each solution was prepared, so students have a sense of the range of sugar concentrations provided. The instructor may need to teach students about the concept of concentration and percent solutions.

- Teach students how to use a balance, including taring.

Lab Protocol

1. Inform students about which of the solutions is probably closest to being isotonic to the egg fluids

(typically, the 5% solution for fresh eggs). Ask students which solutions they predict will be hypertonic and which will be hypotonic relative to the egg fluids. Based on their knowledge of osmosis, have students predict what will happen to the weight of an egg when placed into each solution. Tell them to record their predictions in the table provided in the student handout.

2. Have students record the initial weight (g) of each egg in the table in the student handout (or provide students with a table).

3. Instruct students on how to stagger their measurements (e.g., placing an egg into a solution every two minutes) to improve timing efficiency. (An alternative is to let the eggs soak for an entire day between each weighing in order to achieve more dramatic results.)

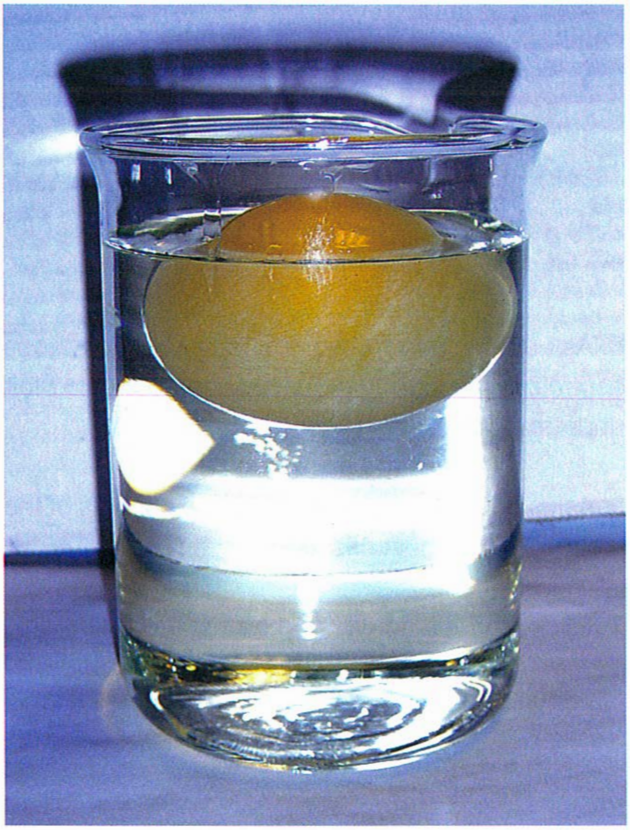


Figure 9.7. Egg in solution

4. Place one egg into the 0% solution, start the timer, and soak the egg for 15 minutes. Repeat for the 5%, 30%, and 50% solutions.

5. After each egg soaks for 15 minutes, remove it with a spoon and carefully dry it with a paper towel.

6. Record the weight of each dried egg in the table in the student handout.

7. Return each egg to its solution and repeat step 6 after 30 minutes.

8. Return each egg to its solution and repeat step 6 after 45 minutes.

Data Display and Analysis

1. Have students calculate and record in the table the overall gain or loss in weight for each egg by giving an example of how the calculation should be performed (final weight minus initial weight equals overall weight gain or loss).

2. Instruct students on constructing a graph that illustrates the change in weight over time for the various solutions. Have them put the results for all four solutions on the same graph for easier comparison.

3. Have students estimate the percent solution that is isotonic to the fluid inside the egg and write down their answer in the space provided on the student handout.

Follow-up Discussion Questions

Review:

1. Give students the opportunity to summarize their observations and data up to this point.

2. Have groups share and compare results.

3. Ask students whether their results matched their predictions.

4. Review the terms *hypotonic*, *hypertonic*, and *isotonic*, and guide students in the correct application of these terms to their results.

Hypotonic = fluid with lower solute concentration relative to another fluid

Hypertonic = fluid with greater solute concentration relative to another fluid

Isotonic = fluids with the same solute concentration

Interpretive:

5. Ask students to relate the results of the lab exercise to osmosis within a cell or organism. Give them some scenarios where organisms or cells are exposed to changes in osmolarity. For example, salmon migrate from seawater to freshwater to spawn. Ask students to predict what will happen to the salmon's cell volumes.

One of the problems with drinking seawater is that it is three times as salty as blood or tissue fluid or cytoplasm. The natural tendency is for the fluid in the cells of the stomach and intestine to lose water to the saltier seawater, thus shrinking the cells and possibly killing them and others. Saltwater fish normally drink seawater, but they have specialized gills that pump salt ions back into the seawater, allowing the fish to keep just the water. Since the gills are thin and filled with capillaries, they are a natural gateway for water flux. If a saltwater fish swims into freshwater, the outflow of water reverses, and the fish may be in danger of gaining too much water. Anadromous fish (salmon, eels, etc.) can alter the capabilities of their gills, compensating for the reversal of water flux, whereas other fish cannot.

6. Ask students to predict how the results of this experiment would differ if older, more dehydrated eggs had been used instead of fresh eggs.

When something dehydrates, water is lost. The ratio of water to dissolved substances—ions for example—changes to a higher proportion of dissolved substances, even though their number has not changed. When this happens, the osmotic potential of the solution is also changed. For example, when eggs dehydrate in storage, they are more likely than fresh eggs to absorb more water if placed into distilled water, and the isotonic point would shift toward a higher osmolarity than the normal isotonic point.

Reflective:

7. Ask students to determine sources of error for the lab.

8. Ask students to freewrite a paragraph on those aspects of the activity that most contributed to their understanding of osmosis.

9. Ask students to freewrite on those aspects of the lab they found most challenging.

10. Ask students to develop and share mnemonic devices for memorizing the terms associated with the process of osmosis.

Formative Assessment

- Students will demonstrate their knowledge of osmosis and of the terms *hypertonic*, *hypotonic*, and *isotonic* in the discussion during the preview section before the lab.
- Students will demonstrate their abilities to identify variables that affect osmosis, formulate testable hypotheses, and design experiments to test those hypotheses during the procedure part of the lab (Guided Inquiry only).
- Students will demonstrate their abilities to decide if data supports a hypothesis during the follow-up discussion part of the lab (Guided Inquiry only).
- Students will show their facility with displaying data and calculating percentages during the procedure part of the lab.
- Students will demonstrate their abilities to make percent (by volume) solutions and use the weighing balance during the procedure part of the lab (Structured Inquiry and Guided Inquiry only).

Summative Assessment

- Ask students to use the Lab Report Template **on page 163** to summarize the experiment in writing. In addition, supply an assessment rubric such as the one found **on page 130**.
- Have students convert the data into a graph that indicates time vs. weight gain or loss, describe the results, and draw some conclusions.

Suggestions for Extended Learning

- Ask students to develop new questions about the process of osmosis and design further experiments that might answer those questions. For example, students could be asked to design experiments with dialysis tubing as the model system. Using dialysis tubing, they have the ability to alter both the internal and external solute concentrations.
- As the terms *hypotonic*, *hypertonic*, and *isotonic* are quite similar, ask students to create mnemonic devices for remembering the differences between the terms. Have them share their mnemonics with the class.

OSMOSIS LAB: STRUCTURED INQUIRY VERSION

Time Required: 4–5 hours

Summary

The Structured Inquiry version of this lab has students generate their own set of solutions to determine the percent solution that is isotonic to egg fluids. Students submerge deshelled eggs in sugar solutions and record changes in egg weight over time.

Learning Outcomes

See Demonstration version

National Science Education Standards: See Demonstration version

Materials

See Materials list for Demonstration version

Activity Sequence

1. Preview the activity, its purpose, background, and learning outcomes

2. Guide students in making the percent solutions they choose to use

3. Procedure: Measuring weight changes in the eggs

4. Data display and analysis

5. Follow-up discussion questions

Procedure

The following adaptations to the Demonstration version procedure would make this a structured inquiry lab:

1. Each student group designs and makes its own set of solutions to determine which percent solution is isotonic to the fluid inside the egg. This can often result in a range of possible outcomes. Groups may generate, for example, all hypertonic solutions, all hypotonic solutions, or some of each, as in the Demonstration version. Each group should nevertheless be able to make a rough approximation of the isotonic point, particularly once all groups have shared results.

2. Because additional time is required for students to make solutions, it may be preferable to prepare them during the previous lab period. Students may also require explicit instruction in how to prepare percent solutions. Instructions for calculating the proportions of reagents are provided in the student handout.

3. Use of alternative sugar sources can be advantageous. For example, dark corn syrup provides visual affirmation of concentration differences, since less-concentrated solutions are paler than more-concentrated solutions. Sucrose (table sugar) as a sugar source may prove more economical than corn syrup.

4. It is recommended that the number of solutions used be limited to four or five for time management and group coordination.

5. Remind students that there are checkboxes in the Procedure section of their handouts to track their progress in completing the lab.

6. See the student handout "Student • Egg Osmosis—Structured Inquiry" in Appendix C for detailed procedure and data analysis.

Follow-up Discussion Questions

These questions are the same as those in the Demonstration version

Formative Assessment

See Demonstration version

Summative Assessment

See Demonstration version

Suggestions for Extended Learning

See Demonstration version

OSMOSIS LAB: GUIDED INQUIRY VERSION

Time Required: 5–5½ hours

Summary

The Guided Inquiry version of this lab has students design an experiment to test the effect of some variable on the process of osmosis. Students will generate their own set of solutions for this version. Deshelled eggs will be submersed in these solutions, and students will record changes in egg weight over time.

Learning Outcomes

See Demonstration version

National Science Education Standards: See Demonstration version

Materials

See Materials list for Demonstration version; in addition, see Procedure that follows for additional materials ideas

Activity Sequence

1. Preview the activity, its purpose, background, and learning outcomes

2. Guide students in designing their experiments

3. Guide students in making the percent solutions they choose to use

4. Procedure: Measuring weight changes in the eggs

5. Data display and analysis

6. Follow-up discussion questions

Procedure

Remind students that there are checkboxes in the Procedure section of their handouts to track their progress in completing the lab.

The following adaptations would make this a guided inquiry lab:

1. Since guided inquiry labs are more open ended, this version allows students the flexibility to investigate how a variable of their choosing affects osmosis, using the egg as a model system. For example, students may choose to vary any of the following:

- Solute type: students could, for example, compare a solute that doesn't dissociate in water (sucrose, 5%) to one that does (NaCl, 5%); *or* compare a salt that dissociates into two particles (NaCl) with one that dissociates into three particles ($CaCl_2$); *or* compare different sugars (e.g., maple syrup vs. corn syrup) to determine which has the highest density
- Temperature (provide a thermometer)
- Egg age (older eggs are more dehydrated than fresh eggs)
- Egg size (smaller eggs have a greater surface area-to-volume ratio than larger eggs)
- Eggs from different species (quail, duck, goose, chicken, etc.)

2. Limit students to studying one variable at no more than three levels to facilitate completion of each group's project in the allotted time.

3. Students may require instruction on controlling all possible variables except the independent variable being studied. If this is the case, provide a sample experiment and ask students to develop a list of variables that should be controlled to achieve optimal results.

4. Student groups should be required to write the protocols for their experiments prior to starting the experiment. This activity ensures that the group sorts out procedures prior to initiating work.

5. Additional prelab prep is required to make this version more manageable for the instructor; for example:

- If the Demonstration version is done first, ask students to design and submit a mini-proposal for their self-designed version prior to leaving that lab. In this way, the instructor can provide some on-the-spot guidance and have required materials available for the next lab period.

- If only the inquiry-based lab is done, provide a restricted list of available materials that can be used to design an experiment.

6. **See the student handout** "Student• Egg Osmosis—Guided Inquiry" in Appendix C for detailed procedure and data analysis.

Follow-up Discussion Questions

These *Review* and *Interpretive* questions can be substituted for questions 1–5 in the Demonstration version.

1. Give students the opportunity to summarize their observations and data up to this point.

2. Review the terms *hypotonic*, *hypertonic*, and *isotonic* and guide students in the correct application of these terms to their results.

3. Ask students to estimate the percent solution that is isotonic to the fluid in the egg in each case. Did their results change or remain the same as a result of their treatment protocol?

4. Ask students to compare their results with those of other groups. What general conclusions can they draw about the process of osmosis and the factors that affect it?

5. Ask students whether their results matched their predictions.

For *interpretive* and *reflective* questions 6–9, see the Demonstration version of this activity.

Formative Assessment

See Demonstration version

Summative Assessment

See Demonstration version

Suggestions for Extended Learning

See Demonstration version

10 ACTIVITIES: GENETICS

Introduction

This section contains three activities that fall under the content area of genetics. They are not intended to be used in the particular sequence in which they are presented. Instructors are encouraged to use them in any sequence that fits their curriculum. A short description of each activity follows.

Mendelian Genetics (page 299). In this activity, students learn the basic patterns of Mendelian inheritance using Punnett squares and Legos to represent genes. The activity is designed to demonstrate both an inductive and a tactile approach to learning these concepts. A supporting student handout and concept map are provided for this activity in Appendix C, "Student•Mendelian Genetics."

Genetics on the World Wide Web (page 307). Students explore various Web sites that teach about genetics through animations and interactive features. No student handout is provided for this activity.

Human Monogenic Traits (page 312). In this activity, students carry out a survey to sample the frequency of human monogenic traits in their school or community. It is designed as a structured inquiry activity in that the instructor offers explicit instructions and procedures, yet students are pressed to draw their own conclusions. It also includes an optional component in which students use an explicitly taught statistical test to determine the significance of their results. A complete student handout is provided in Appendix C, "Student • Human Monogenic Traits."

Mendelian Genetics

Time Required: 60 minutes

Summary

This activity provides a concrete experience and analogy for students in building their understanding of key introductory genetics principles. It is inductive by design. **See page 102** for an overview of "Inductive and Deductive Teaching Approaches." The activity should be carried out after some prior-knowledge assessment for a genetics unit has been done, and after students have been given a basic introduction to genes and chromosomes. A short video clip that shows this activity is included on the CD found on the inside front cover of this manual.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Associate genes and genotype with traits and phenotype
- Use Punnett square analysis to predict the genotype and phenotype of offspring
- Define and correctly apply the following genetic terms: *allele, genotype, phenotype, heterozygous/heterozygote, homozygous/homozygote, dominant allele/dominance, recessive allele/recessiveness*

National Science Education Standards: Content Standard C:2:2 (see Appendix B)

Materials

- Two small, distinct shapes representing alleles:
  — Examples: Legos or wooden blocks; any materials that fit into containers described under next bullet
  — 14 pieces of one shape and 14 pieces of another shape are needed per team
  — The exercise as described here uses black 2cm x 2cm Lego square bricks and Lego steep slope roof tiles (**see the source note** at the end of this activity)

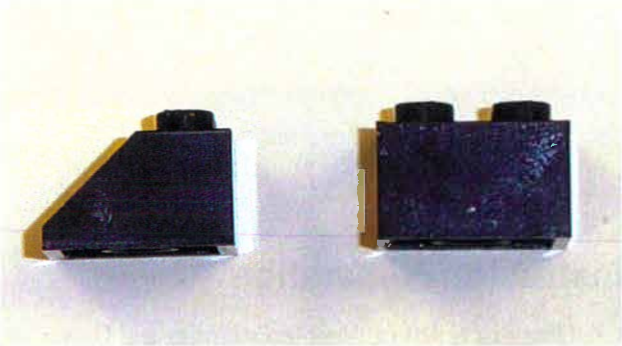


Figure 10.1. Materials (A): two distinct Lego shapes representing alleles

Note: This activity was inspired by one authored by Anne Buchanan and found at the Access Excellence Web site: http://www.accessexcellence.org/ (AE/ATG/data/released/0256-AnneBuchanan/index.html; link now discontinued) (permission granted to cite)

Source Note for Materials: Lego, P.O. Box 1310, Enfield, CT 06083; www.lego.com; 2x2 brick, Item #3495; 2x2 steep slope roof tile, Item #3453

Figure 10.2. Materials (B): Lego square and Lego steep slope roof tile representing alleles, one colored container with lid representing an organism/phenotype, and a container with extra Legos

- Two distinctly colored containers *with lids* that represent individuals:
  - — Examples: film vials, painted plastic organism containers from biological supply companies, plastic Easter eggs, coffee cups
  - — The exercise as described here uses five red and six blue colored containers per team

- Poster-size paper

- Punnett square template handout (**see Appendix C**, "Student•Mendelian Genetics 7")

Instructor Preparation

- Prepare a set of three containers per team, as follows:
  - — Blue, containing two bricks
  - — Blue, containing one brick and one roof tile
  - — Red, containing two roof tiles
- Prepare a Lego "extras" container for each team and place 11 of the Lego bricks and 11 roof tiles within (this can be any kind of container)
- Prepare a group of 4 additional containers of each color (8 overall) for each team
- On the poster-size paper, draw a Punnett square showing the cross described in Procedure Part B, step 1 (ideally, Legos should be glued or taped in the Punnett square boxes, but they could also be drawn with a black marker).
- Copy one Punnett square template per student group (**see Appendix C,** "Student•Mendelian Genetics").
- Make copies of the student handout, one for each student (**see Appendix C,** "Student• Mendelian Genetics").

Activator/Connector

Ask students what color their eyes are and what color their parents' eyes are. Make a table on the board with student responses; then ask why brown-eyed students must have at least one brown-eyed parent, while blue-eyed students can have blue-eyed or brown-eyed parents. (*Important note:* The inheritance of eye color is a complex polygenic system and cannot be explained in a simple blue-eye/brown-eye model. The purpose here is not to get into the complexity of eye-color inheritance, but to probe students' background knowledge and motivate them toward the upcoming lesson.)

Activity Sequence

1. Preview the learning outcomes

2. Students become familiar with hands-on materials used to show genetics principles (Procedure Part A)

3. Students use materials to perform "virtual matings" that show inheritance principles (Procedure Part B)

4. Key genetics terminology is introduced by instructor (Procedure Part C)

5. Complete follow-up discussion questions

Procedure

Part A: Introducing the Legos

1. Preview generalized learning outcomes without specificity (to allow students to become familiar with key genetics terms and concepts).

2. Review or introduce the concepts of genes and chromosomes.

3. Give each student team the following:
   a. A set of containers (two blue and one red) containing the three Lego combinations described in Instructor Preparation.
   b. A Lego "extras" container with 11 bricks and 11 roof tiles.
   c. A stack of additional containers, four red and four blue.

4. Puzzle challenge:
   a. Tell the class that every team is getting the same materials for this activity.
   b. Ask them to examine the containers and their contents.
   c. When they are ready, ask students to describe the contents of the containers. Discuss responses as a class.
   d. Distribute the student handout packet. Have students record their observations on the diagram in Part A (also **shown in Figure 10.3**).
   e. Clarify discrepancies as necessary.
   f. Tell the students that the blocks inside the containers affect the outside color.
   g. Challenge them to come up with a rule that accounts for their observations (e.g., presence

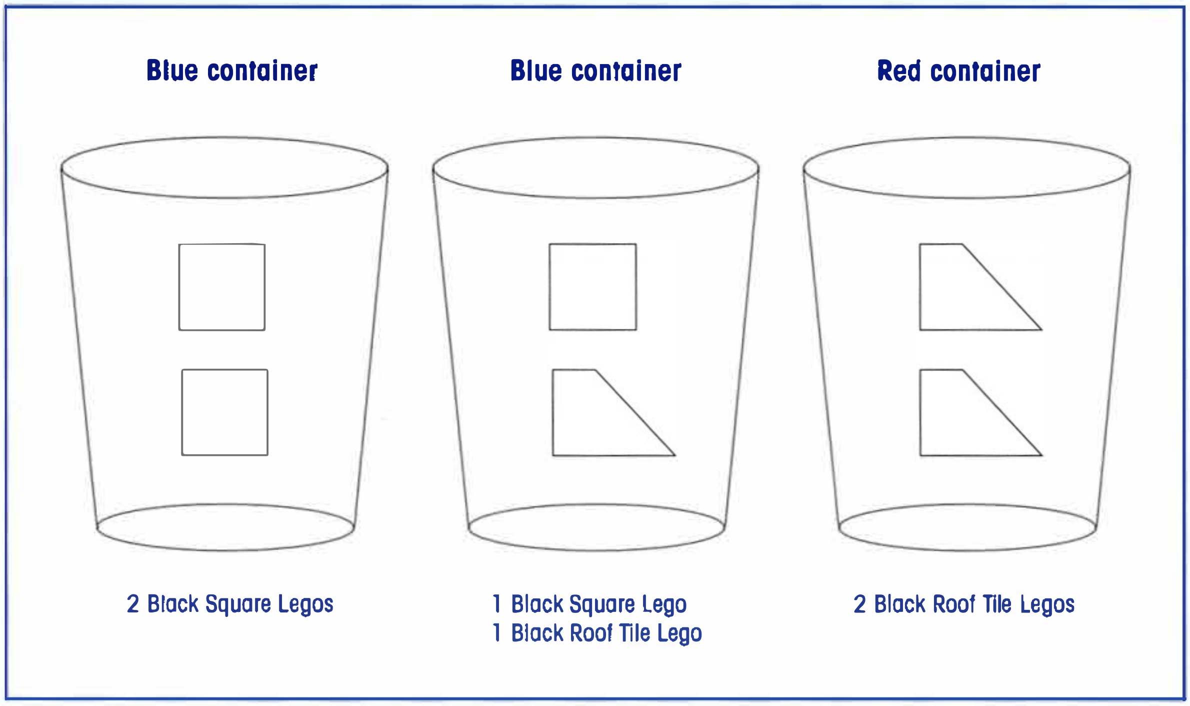


Figure 10.3. A representation of the containers and their contents

of at least one brick = blue color; presence of two roof tiles = red color).

h. Tell the students they will come back to this idea later on.

5. Analogy to genetics:
   a. Explain the purpose of the materials and the activity: the containers and Legos provide a concrete analogy and model for understanding basic genetic principles and key genetic terminology.
   b. State the analogy and write it on the board:
      - container = organism
      - container's color = trait
      - Legos = genes that determine the color
   c. Ask students why they think each organism has two genes for determining color. (*Answer: one gene was received from each parent, leading to two copies in an organism/container*). Relate this to the idea of paired chromosomes.
   d. Explain the concept of *allele:*
      - Write on the board the definition of alleles: *Genes for a trait that come in different versions or variations*

        gene = Lego; alleles = brick and roof tile variants

        gene is ice cream flavor; alleles are strawberry and chocolate varieties

      - Allelic combinations determine the organism's characteristics (e.g., two bricks = blue; one brick/one roof tile = blue; two roof tiles = red)

Part B: Introducing the Punnett Square

1. To help understand how the inheritance and interplay of alleles affects the color of offspring, tell students they will mate the blue container (two bricks inside) with the red container (two roof tiles inside). Tell students that an organism's sex is not important for this and other matings to follow.

2. Explain how to mate the containers and determine their offspring using a tool called a Punnett square.

3. Use of the Punnett square template:
   a. After passing out the template, explain that it is a tool to understand how genes are passed from parents to offspring by identifying all possible allelic combinations in offspring.
   b. Students should open the two containers they will mate to clearly see their contents.
   c. Place the containers next to and above the "parent" spots on the template.
   d. Tell students to take two bricks from the "extras" container and place them in the big arrows that represent the blue parent's genes. (Do not remove original Legos from the containers! This is so that mix-ups will not occur.)
   e. Repeat step d for the red container's genes.
   f. Using the premade poster paper, model how to distribute the alleles/Legos inside the Punnett square so that each parent donates only one of two alleles/Legos to any one offspring. Explain how this connects to the law of segregation, if desired. **(See Figure 10.4)**
   g. Discussion questions for the entire group:
      - How many allele/Lego combinations are possible? *1 possible*
      - What is the probability (chance) of getting each combination? *4/4 or 100%*
      - What color(s) will the offspring be? *All blue*
   h. To make the "Lego/Cup" connection crystal clear, ask students to take four of the extra blue

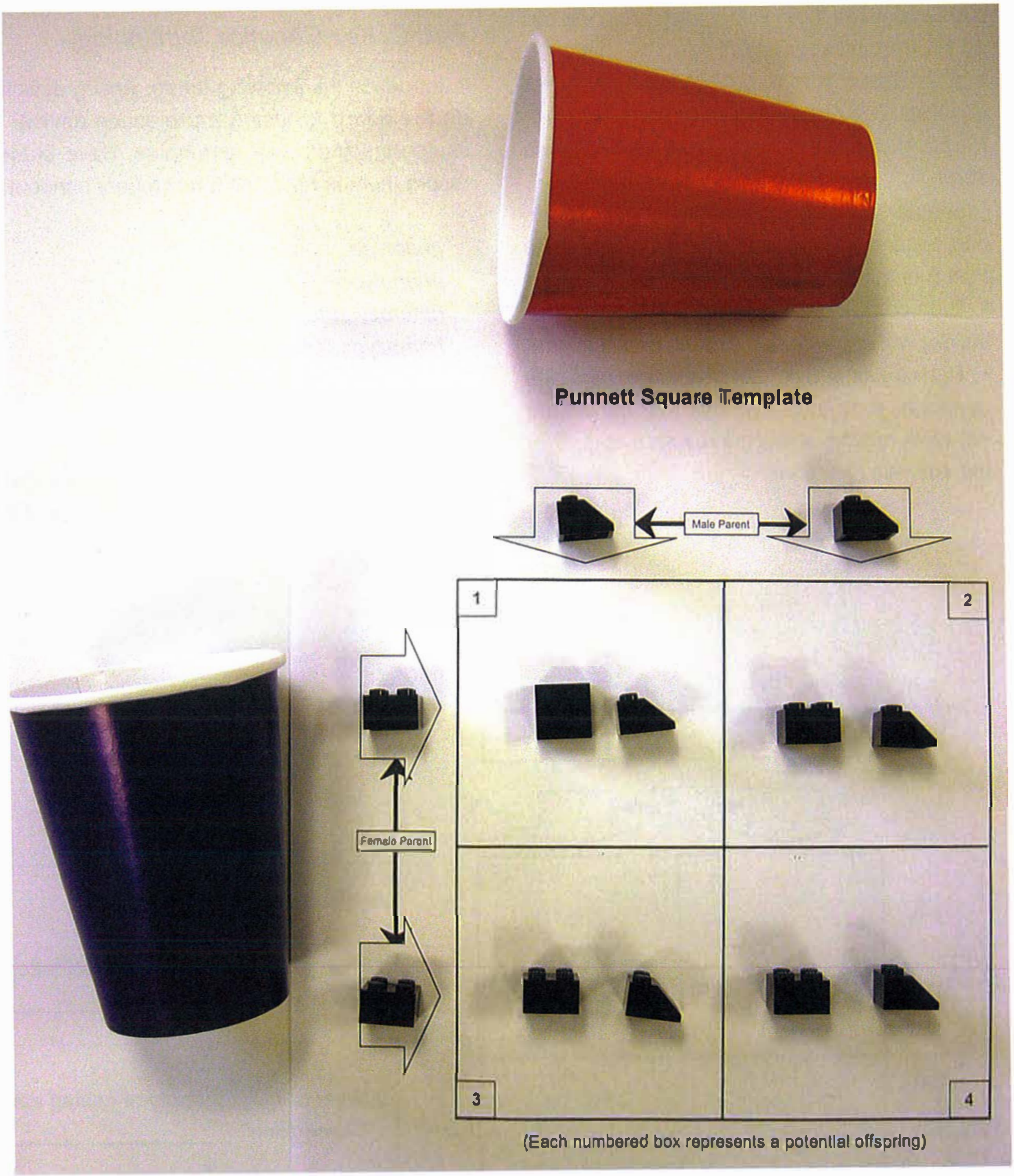


Figure 10.4. Legos distributed in Punnett square template

cups and place them within each offspring box on the Punnett square template.

i. Instruct students to fill out the Punnett square template and answer the analysis questions in Part B of their student handout. (**See Figure 10.5**)

j. Students should complete the following Punnett square matings and record the results in Part B of their handout:

- Blue container (one brick and one roof tile inside) with blue container (two bricks inside)
- Red container (two roof tiles inside) with blue container (one brick and one roof tile inside)

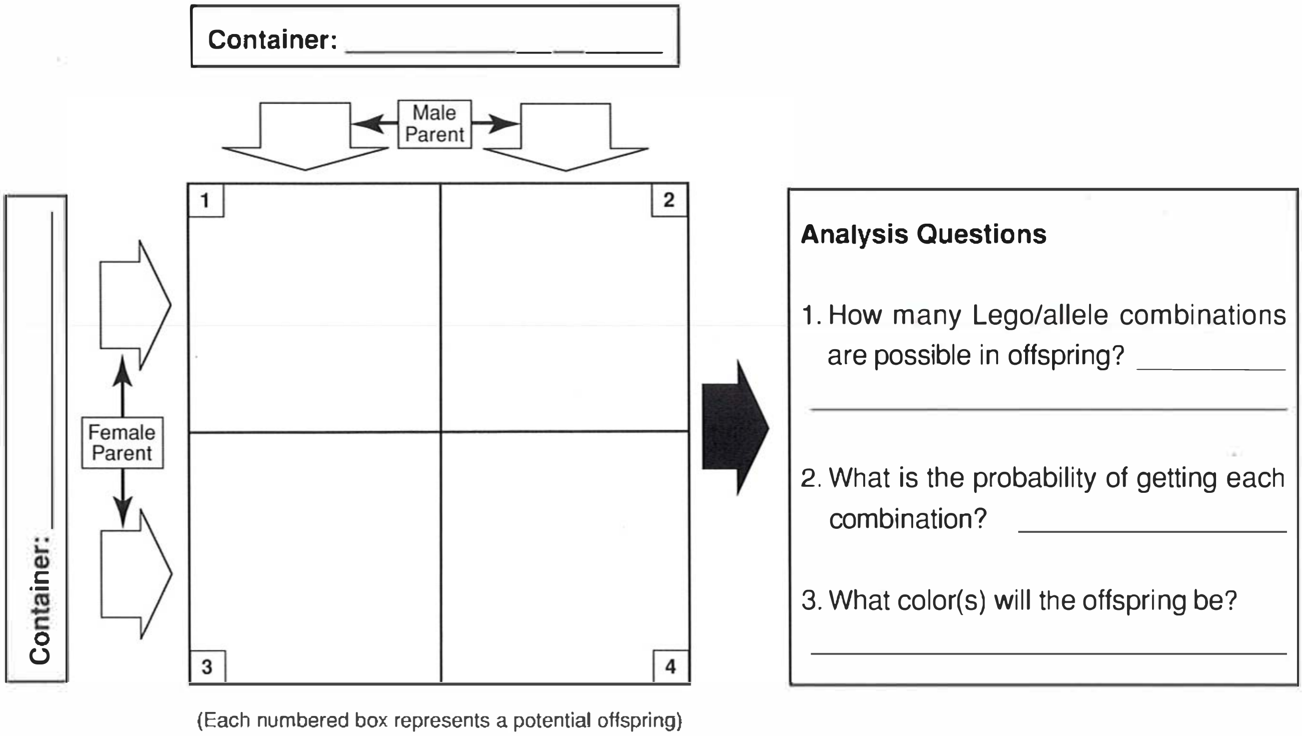
k. For each mating, share the results and go over the analysis questions.

Part C: Key Genetics Terminology

1. Introduce the following terms, writing definitions on the board, or using a projection device, and illustrating them with examples. Have students record them in Part C of their student handout.

genotype
phenotype
heterozygous/heterozygote
homozygous/homozygote
dominant allele/dominance
recessive allele/recessiveness

2. Discuss phenotypic and genotypic ratios, demonstrating with the matings performed in Part B (optional).



Analysis Questions

1. How many Lego/allele combinations are possible in offspring? ___

___

2. What is the probability of getting each combination? ___

3. What color(s) will the offspring be?

___

(Each numbered box represents a potential offspring)

Figure 10.5. Punnett square template

Follow-Up Discussion Questions

Review:

Note: In the following tasks, students demonstrate their understanding with actions, not words. The easiest way to do this is to have all students hold up and use the appropriate materials to show their answers to the prompts listed below. This is a quick way to assess student understanding and to identify and correct discrepancies. It also recognizes those students who understand through their hands but have difficulty using language to share their understanding.

1. Post these tasks for all to see, so students can have a visual reference. Ask students to demonstrate the following:

a. Show two possible phenotypes.

Students will hold up the two colored containers.

b. Show the heterozygous genotype.

Students will hold up the roof tile/brick combination.

c. Show a recessive allele.

Students will hold up the roof tile.

d. Show three possible genotypes.

Students will hold up the two bricks, the two roof tiles, and the roof tile/brick combination.

e. Show a dominant allele.

Students will hold up the brick.

f. Show the homozygous genotypes.

Students will hold up the two bricks and the two roof tiles.

2. To apply their learning, ask students, using the Punnett square template, to determine potential offspring genotypes, phenotypes, and their ratios for all possible matings that have not been discussed:

a. Homozygous blue container x homozygous blue container

b. Homozygous red container x homozygous red container

c. Heterozygous container x heterozygous container

Have them record their work in Part D of the student handout.

Interpretive:

3. Analyze the Lego/colored container analogy used in this exercise for its genetic accuracy.

a. What is accurate?

Genes do affect an organism's color. Genes come in different forms (alleles) that at a molecular level have different shapes, just like the Legos.

b. What is oversimplified?

Color tends to be affected by more than one set of genes.

Note: It is important to fend off larger misconceptions whenever possible.

Reflective:

4. Ask students to reflect on how well this analogy helped them learn the genetics terms and principles introduced.

Formative Assessment

- Students will demonstrate their understanding of the relationship between genotype and phenotype in class by completing question 1 of the follow-up discussion part of the activity.

- Students will demonstrate their understanding of the genetic terms *homozygous*, *heterozygous*, *recessive*, and *dominant* in class by completing question 1 of the follow-up discussion part of the activity.

- Students will demonstrate their abilities to use Punnett square analysis to predict genotypes and phenotypes during Procedure Part B and question 2 of the follow-up discussion part of the activity.

Summative Assessment

- If students are familiar with concept maps, ask them to generate a concept map that includes the following concepts: *genes, alleles, homozygous, heterozygous, dominant, recessive, genotype, phenotypes, chromosomes.*

- Alternatively, assign a fill-in-the-blank concept map such as the example found **in Appendix C**, "Student•Mendelian Genetics 8."

Suggestions for Extended Learning

- Once students have mastered the terms and their tactile representations, introduce more traditional representations of Punnett squares using letter codes (i.e., AA or aa) and classic genetics problems.

- Use this same Lego/container set-up and enhance it to teach additional concepts such as incomplete dominance, codominance, and dihybrid crosses.

Incomplete Dominance: This could be done by adding a new cup color, such as purple, to the activity's materials.

Codominance: The classic A-B-O blood-type example of codominance could be modeled by adding another Lego shape to the mix, as well as two more container colors (for instance, Blue = A type; Red = B type; Purple = O type; and Blue-and-Red Striped = AB type)

Dihybrid Crosses: A dihybrid cross would be a lot more complex than the monohybrid cross, but possible. It would require

— a 16-box Punnett square template

— an additional phenotypic trait besides container color (such as two different lid styles)

— four different Lego shapes (two new ones for the lid styles, for instance, plus the originals)

Genetics on the World Wide Web

Time Required: variable

Summary

Using Web sites selected by the instructor, students utilize the graphic advantages of the World Wide Web to explore key genetics concepts, such as the structure of DNA, protein synthesis, chromosomes, and genes. See "Using the Internet and CD-ROMs in the Biology Curriculum" beginning **on page 165** for ideas on evaluating and choosing Web sites for students with learning differences.

Learning Outcomes

After completing this activity, students will be able to:

Content

- Define terms (as determined by instructor) associated with some or all of the following areas of genetics: general DNA and chromosome structure and function, the processes of transcription and translation, mutations, gene structure, and sequence analysis
- Demonstrate knowledge of key genetic concepts through class presentation (optional)

Computer Skills

- Locate and navigate Web sites on concepts in genetics

National Science Education Standards: C:2:1, C:2:2, and C:2:3 (see Appendix B)

Materials

- Computers with Internet access, as well as Flash and Shockwave plug-ins
- Question guides for each site to focus student explorations
- Digital projection device

Instructor Preparation

Before the activity, instructors will need to do the following:

- Preview the Web sites described below to determine if they are still active
- Decide which active sites best suit their teaching objectives. For instance, an instructor could use these sites to introduce some new genetics concepts or to review and enhance student understanding of concepts previously encountered during the course
- Decide whether to have students work in pairs or alone
- Decide how many sites an individual or team will explore
- Decide whether or not to modify the "sample guiding questions" in Procedure Part A to suit their teaching objectives
- Reserve a computer lab where the activity can take place and load, if necessary, the plug-ins needed to run some of the Web activities

- Devise a quick and efficient method for students to access the URLs described in Procedure Part A, such as a Web page that contains the links

Activator/Connector

What does a gene look like? Ask students to draw their depictions of a gene and share them with the class. Use this as a segue to suggest that the graphic powers of the World Wide Web can make the abstract nature of genetics more concrete and easier to understand.

Activity Sequence

1. Preview the activity, its purpose, background, and learning outcomes

2. Student exploration of Web sites assigned by instructor (Procedure Part A)

3. Student presentations on Web sites (Procedure Part B—optional)

4. Follow-up discussion questions

Procedure

Part A: Web Site Descriptions

The Web sites described in this section offer activities and animations to help students explore and understand key genetics concepts. We have supplied a description of the main features of each site and a list of focusing questions to guide students in using the sites effectively. Teachers may assign one or more sites or Web explorations for each student or student team. The sites are arranged from most basic to most advanced.

1. Journey into DNA
http://www.pbs.org/wgbh/nova/genome/dna.html (needs Flash plug-in)
From NOVA: *Cracking the Code of Life* http://www.pbs.org/wgbh/nova/genome/

This activity is a 15-slide animation that allows the user to view smaller and smaller levels of genetic detail, starting with the human body and ending with the atomic structure of DNA bases. It even includes a rhyming verse that accompanies the animation. It provides a meaningful sense of scale for understanding the relationship of cells and DNA.

Sample Guiding Questions

- How many cells are there in the human body?
- What is the range of gene length in terms of bases?
- What is the role of histones?
- Rank the following structures from largest to smallest: nucleosome, cell, gene, chromosomes, nucleotide, bases, DNA, chromatid, nitrogen, atom, nucleus

2. Build a DNA Molecule
http://gslc.genetics.utah.edu/basic/builddna.html
From Genetics Science Learning Center at http://gslc.genetics.utah.edu/index.html

This short activity allows students to see and manipulate the base pair combinations in a DNA strand. This would be most appropriate for groups with little background knowledge about the structure of DNA.

Sample Guiding Questions

- Describe the pairing of DNA bases in the DNA strand.
- What do you think the "crunching" sound

represents biologically when the nucleotides are dragged into their locations?

3. Tour of the Basics

http://gslc.genetics.utah.edu/basic/basics.html (requires a Flash plug-in)

From Genetics Science Learning Center at http://gslc.genetics.utah.edu/index.html

This primer activity contains six different modules: What Is DNA? What Is a Gene? What Is a Chromosome? What Is Inheritance? What Is a Protein? What Is Meiosis/Mitosis? A teacher could assign any single module or a combination of the modules in any order. This would be most appropriate for groups just encountering these ideas for the first time, or as a method of review.

Sample Guiding Questions for the What Is a Chromosome? module

- Describe the role of chromosomes for an organism.
- Describe the sex chromosomes.
- Compare chromosome numbers across species.

4. Transcribe and Translate a Gene

http://gslc.genetics.utah.edu/basic/transcribe.html

From Genetics Science Learning Center at http://gslc.genetics.utah.edu/index.html

This activity introduces the process of protein synthesis. It takes students through the transcription and translation phases and simulates the production of an amino acid sequence. It demands a working knowledge of DNA structure and the function of genes; therefore, it is more advanced.

Sample Guiding Questions

- Describe the following:
  a. transcription
  b. translation
  c. central dogma of biology
  d. messenger RNA
  e. codon
  f. amino acid
- Why do you think there is a "stop" codon?
- Name an imaginary function for the protein you made.

5. What is a Mutation?

http://gslc.genetics.utah.edu/thematic/nf1/proteinrole/sentence.asp

From Genetics Science Learning Center at http://gslc.genetics.utah.edu/index.html

This activity is a primer on mutations. The main goal is to reinforce the codon/amino acid relationship and demonstrate four different kinds of mutations: silent, frameshift, nonsense, and missense. It supplies background information and tasks that apply the information presented. It requires a good working knowledge of DNA structure and function and basic protein synthesis.

Sample Guiding Questions

- How is a sentence like a gene? How is a word like a codon? How is a misspelling like a mutation?
- What codon and amino acid do all genes start with?
- What is the amino acid sequence encoded by the DNA sequence presented in the activity?
- What does a missense mutation look like? How does it change the amino acid sequence?
- What does a nonsense mutation look like? How does it change the amino acid sequence?
- You can make more than one frameshift mutation. What do they look like? How do they change the amino acid sequence?
- Notice how a single amino acid can be encoded by a number of different codons. What are some examples of silent mutations in the DNA sequence?

6. Explore a Stretch of Code
http://www.pbs.org/wgbh/nova/genome/explore.html (requires Shockwave)

From NOVA: *Cracking the Code of Life* http://www.pbs.org/wgbh/nova/genome/

This activity shows a section of human chromosome #1 and its specific sequence of bases. It demonstrates the terms *gene*, *introns*, *exons*, *gene promoters*, and others. It also demands a basic working knowledge of DNA structure and function.

Sample Guiding Questions

- Briefly describe the following:
  a. hitchhiker code
  b. start codon
  c. stop codon
  d. intron
  e. extron
  f. site of variation

7. Sequence for Yourself
http://www.pbs.org/wgbh/nova/genome/sequencer.html (Flash plug-in required)

From NOVA: *Cracking the Code of Life* http://www.pbs.org/wgbh/nova/genome/

This activity is a self-paced tutorial animation that shows how the Human Genome Project uses restriction enzymes and bacterial culturing to identify the precise sequences of DNA bases on each of our 23 chromosomes. It is appropriate for students with a good background in molecular biology.

Sample Guiding Questions

- What is the role of restriction enzymes?
- What is the role of the vector?
- What is the purpose of cloning the DNA fragments?
- What is the role of the special nucleotides?
- What is the role of the electrophoresis process?
- How is the computer used?

Part B: Web Site Presentations (optional)

Have students give brief oral presentations on the site they explored. This would require a digital projection device for the whole class to see the Web sites.

Suggested Guidelines

- Be brief—five-minute maximum per team or individual
- Use the graphics of the Web site to show 2–3 key ideas learned, using the teacher-provided guiding questions

Follow-up Discussion Questions

Review:

1. Write down one important and interesting concept or idea you have encountered from each Web site visited.

2. If someone asked you to explain DNA in one sentence, what would you say?

Interpretive:

3. Why do you think problems can arise if an individual human has more than 46 chromosomes in each of his or her cells, or fewer than 46?

More or fewer than 46 chromosomes create problems in cell division and gene expression, leading to dysfunctional genes.

Reflective:

4. Freewrite for a few minutes on the advantages and disadvantages of using the Web, as compared to a text, to access this kind of information.

5. Was this kind of activity a good match for your learning style?

Formative Assessment

Students will demonstrate their abilities to define and describe selected key terms in genetics and navigate the Web sites during Procedure Part A (Web site exploration), Procedure Part B (optional student presentations), and the follow-up discussion parts of this activity.

Summative Assessment

Provide students with a list of the key terms and concepts that they need to understand. Also supply them with the links to the Web sites used in the activity, so that they can review and enhance their understanding of the concepts. Give a quiz based on the key terms and concepts and include varied ways for students to show their understanding of the terms and concepts.

Suggestions for Extended Learning

Assign or have students locate one more Web site that deals with some aspect of genetics and submit a list of questions to be answered based on the information on that site. Have them switch "sites" with another student and complete the accompanying questions.

Human Monogenic Traits

Time Required

Day 1: Introduction/Set-up: 45 minutes
Day 2: In-class Follow-up: 60–75 minutes
Statistical Option: 45–60 minutes

Summary

This activity uses a classic set of simple monogenic human traits (tongue rolling, etc.) as a springboard for students to design an experimental protocol and collect and analyze data to determine the allele frequencies for these traits in the local population (school, community). It also attempts to address the widely held misconception that dominant alleles are more common or abundant than recessive alleles in a population. It includes an optional section that applies a statistical test to the data collected.

It is most appropriate to introduce this activity after students are already familiar with the basic Mendelian genetics concepts of genotype, phenotype, heterozygous, homozygous, recessive, dominance, sex-linked traits, alleles, and monogenic trait. In addition, familiarity with population genetics concepts such as allele frequencies and gene pool would be helpful but are not necessary.

Learning Outcomes

After this lab activity, students will be able to:

Content

- Define a monogenic trait
- Distinguish the phenotypes for several human monogenic traits
- Differentiate between allele dominance and allele frequency
- Distinguish between sex-influenced traits and sex-linked traits (optional)

Inquiry Skills

- Identify some basic principles of survey design
- Calculate percentages
- Use clear language to accurately describe results from a data table
- Following data analysis, decide if a set of data supports a hypothesis
- Following statistical analysis, decide if a set of data supports a hypothesis (optional)

National Science Education Standards:

Content Standards A:1:1, A:1:2, A:1:3, A:1:4, A:1:6, A:2, and C:2:2 (see Appendix B)

Materials

- Student handout (**see Appendix C**, "Student• Human Monogenic Traits")
- PTC paper and control paper (available through biological supply companies)
- Calculators for data analysis

Instructor Preparation

- Decide which monogenic traits to include in the survey. **See Instructor Background Sheet** for

Monogenic Traits **on page 317** for some choices

- Copy the student handout for this activity
- Decide whether to include the statistics component of the lab
- Gather the items on the Materials list
- Instructors may wish to make additional copies of the survey data collection sheet from the student handout in case they are needed

Activator/Connector

Use the following activator to get students interested in the survey to follow:

How many students have known someone with polydactyly?
How many students can roll their tongue?
How many of you have urine that smells "sulfury" after you eat asparagus?

Activity Sequence

Day 1:

1. Preview the activity, its purpose, background, and learning outcomes

2. Part A—Introduce easily detected human monogenic traits

3. Part B—Design a survey to answer the investigative question

4. Part C—Perform the survey and collect data (homework)

Day 2:

5. Part D—Share results of the survey and calculate percentages

6. Part E—Optional statistical analysis (z-test)

7. Follow-up discussion questions

Procedure

Part A: Introduction to Monogenic Traits

Remind students that there are checkboxes in the Procedure sections of their handouts to track their progress in completing the lab.

1. Review the concept of monogenic traits vs. polygenic traits.

2. Introduce the investigative question: *Are phenotypes associated with the dominant allele generally found more frequently in a population than phenotypes associated with the recessive allele?* Discuss the question as a group. Have students record their answers and reasoning on this question.

3. Introduce each of the monogenic traits selected for the survey, and have students record the phenotypes for each trait in the table provided in their student handouts. Be sure to instruct them on the proper use of the index finger length "T" grid (**see page 321**), and model the proper use of the PTC paper and its control.

4. Make sure that each phenotype is represented in the class for all to see, or provide students with pictures of the phenotypes not present among the students.

5. Share initial results by tallying the number of students with each specific phenotype for each trait under study.

6. Share with students the genotype information for each of the traits to be included in the survey. For example, explain that tongue rolling is controlled by a dominant allele, while the inability to roll the tongue is controlled by a recessive allele. Have them record genotype information in their trait table. See Instructor Background Sheet for Monogenic Traits **on page 317** for specific genotype information.

7. Discuss the possible biological advantages and disadvantages of any of the traits included.

Part B: Survey Design

1. Explain to students that they will be designing a survey that they will administer in the school or local community that attempts to answer the investigative question introduced and discussed in Part A, step 2:

Are phenotypes associated with the dominant allele generally found more frequently in a population than phenotypes associated with the recessive allele?

2. Give students time, and other parameters deemed necessary, to design a survey that will provide data to answer the investigative question. Consider using teams to design a study protocol. If choosing to include polydactyly in the survey, be sure to model an appropriate interview question that takes into account the sensitive nature of this trait.

3. Discuss and compare survey designs and ideas across the class, and decide collectively which ideas and protocols to include. Have students record key features of the survey protocol decided upon. Key issues to resolve include sample size, consistent data collection, and interview protocols across the class, and consistent student tabulation of the raw data.

4. Preview with students the Survey Data Collection Sheet from the student handout (**see Appendix C**, "Student•Human Monogenic Traits 10").

5. Run a sample survey interview within the class to model and clarify appropriate survey procedures.

Part C: Data Collection

Assign students to collect their data as homework.

Part D: Data Analysis

1. When all data are collected, ask students to summarize their individual data in Table A: Summary of Individual Data, page 12 in the student handout.

2. Lead students in recording all class data that was collected in the first three blank columns of Table B: Composite Class Data for All Individuals Surveyed, page 12 in the student handout. Using an overhead projection device will allow all students to record data with a visual reference available.

3. Assign students the task of turning the raw numbers from the second and third blank columns of Table B into percentages. These should then be recorded in the last two columns of Table B. For instance, what percentage of people surveyed could roll their tongue? As some students in introductory biology may have weak math skills, it may be necessary to provide instruction on how to calculate percentages. Be sure to compare the percentages calculated across the class for accuracy.

Part E: Statistical Analysis (optional)

1. Introduce Investigative Question B: *Is there any reason to believe that the frequency with which dominant traits are expressed differs between the genders? For example, do women express more dominant traits than men, or vice-versa?* Have students discuss and record thoughts on the student handout.

2. Preview the purpose (determining significance) and steps involved in performing the z-score. **See student handout** (Appendix C, "Student • Human Monogenic Traits 5") for the procedural steps for calculating the z-score.

3. Help students to share their individual data on the number of dominant traits for each male and each female they surveyed. Assist them in carrying out the calculations necessary to arrive at a z-score, which are contained in the student handout. It is advisable to match students in pairs, ideally with one strong math student per team.

4. Discuss and compare z-scores across the class.

Follow-up Discussion Questions

Review:

1. Have students make general statements that describe the results, orally or in writing.

2. Have students analyze the data to answer this question: *In this school or local community, which of the two phenotypes for each of the monogenic traits surveyed is more common?*

3. Have students analyze the data to answer this question: *Are any of the phenotypes more common in women than they are in men?*

Interpretive:

4. Have students relate the data collected to Investigative Question A: *Are phenotypes associated with the dominant allele generally found more frequently in a population than phenotypes associated with the recessive allele?* What are their conclusions? Does the data support their original prediction/hypothesis? Why or why not? If not, how would they revise their hypothesis?

Student data may vary, but some traits (polydactyly) that are controlled by the dominant allele are much less frequent in the human population. Most of the traits suggested in this activity show that phenotypes associated with the dominant allele are *found more frequently in a population.*

5. Have students relate their findings to Investigative Question B posed in procedure Part E: *Is there any reason to think that the frequency of the traits under study will be different between the genders?* Does the data support your original prediction and hypothesis? Why or why not? If not, how would you revise your hypothesis?

The data on the short index finger trait will ideally reveal a difference between the genders; see instructor background sheet. Otherwise, the frequencies should not differ between the genders.

Reflective:

6. Ask students what was the most difficult part of this activity for them?

7. What did they like?

8. What would they change?

Formative Assessment

- Students will demonstrate their knowledge of the phenotypes of a set of human monogenic traits through their oral participation in Procedure Parts A, B, and C as well as the follow-up discussion section of the lab.

- Students will demonstrate their understanding of some basic principles of survey design through the discussion of how to design and run the survey in Procedure Part B of the lab.

- Students will demonstrate their abilities to accurately describe the survey findings and decide if a set of data supports a hypothesis orally during the follow-up discussion part of the lab.

- Students will demonstrate their understanding of the difference between allele dominance and allele frequency and the difference between sex-influenced and sex-linked traits orally during the follow-up discussion part of the lab.

- Students will demonstrate their abilities to calculate percentages during the data analysis part of the lab.

- Students will demonstrate their abilities to decide if a set of data supports a hypothesis in the follow-up discussion part of the lab.

Summative Assessment

- Ask students to use the Lab Report Template **on page 163** to summarize the survey in writing. In addition, supply an assessment rubric, such as the one found **on page 130**.

- Assign the following question as an out-of-class assignment or for inclusion on the next quiz: Can a recessive allele be more common in a population than a dominant allele? Explain with a real or fictional example.

Suggestions for Extended Learning

- Assign students to research some "famous" monogenic disease traits, such as cystic fibrosis, albinism, Huntington's disease, or progeria. Are these diseases associated with dominant or recessive alleles?

- Assign the following question for students to address in writing:

  Assuming we could cross humans in our genetics laboratory, how would you determine if the earlobe attachment allele (or any other alleles for a certain trait studied) is dominant or recessive? Lay out your research plans carefully and in detail.

INSTRUCTOR BACKGROUND SHEET FOR MONOGENIC TRAITS

The following are descriptions of several human monogenic traits.

A. Tongue rolling(T/t)—the ability to curl the sides of the tongue upward to form a tube. The dominant allele produces tongue rolling.

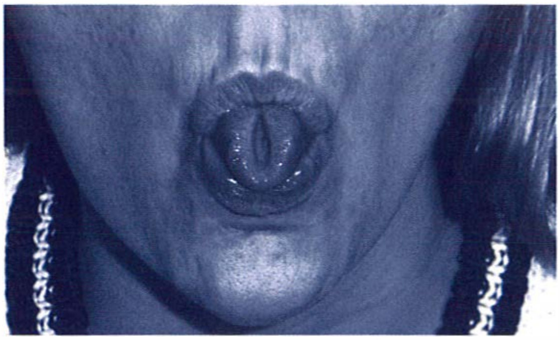


Figure 10.6. Tongue rolling example

B. Handedness (H/h)—the primary use of the right vs. the left hand in writing, throwing, etc. A dominant allele produces right-handedness.

C. Mid-digital hair (D/d)—the presence or absence of hairs on the middle section of fingers. The dominant allele produces hair on at least one finger.

Figure 10.7. An example of mid-digital hair

D. PTC sensitivity(P/p)—The ability to taste PTC, or phenythiocarbamide, is due to the presence of di-iodotyrosine in saliva. Di-iodotyrosine is an amino acid precursor to certain thyroid hormones. The dominant allele produces the ability to taste PTC paper, an extremely bitter taste.

E. Earlobe attachment (E/e)—The dominant allele produces the trait of earlobes that are "free." Attached earlobes is a homozygous recessive trait.

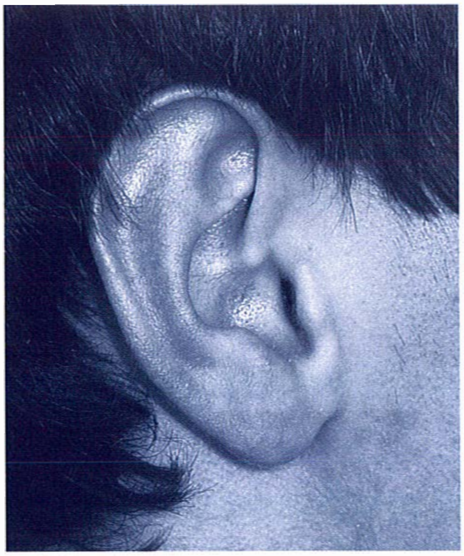


Figure 10.8. An example of "free" earlobe

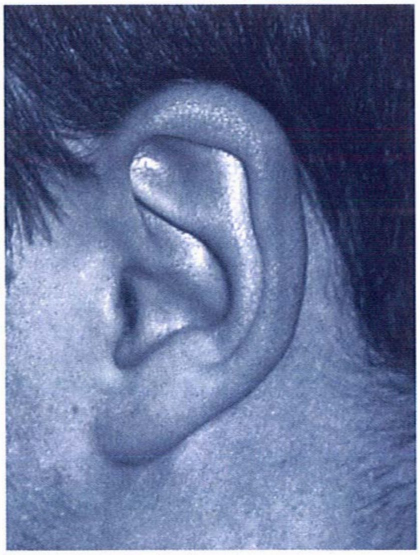


Figure 10.9. An example of attached earlobe

F. Widow's peak (W/w)—A dominant allele produces a hairline that forms a distinct downward point (or "peak") in the middle of the forehead. No widow's peak is the recessive phenotype.

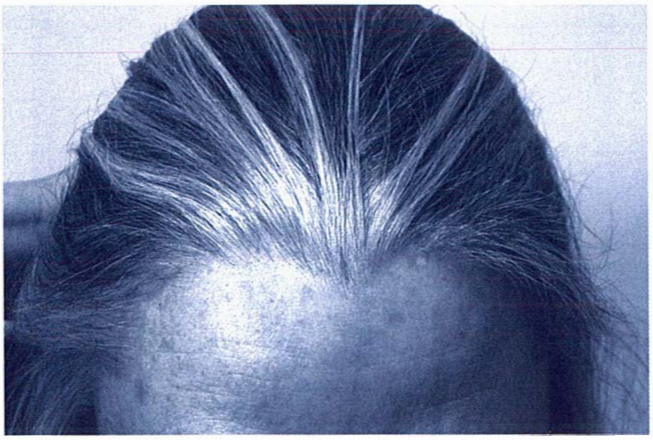


Figure 10.10. An example of widow's peak

G. Polydacytly(F/f)—A dominant allele produces this condition, in which an extra digit is present on hand(s) or feet. This trait is included because it clearly shows the idea that dominant does not necessarily mean common. It occurs in about one out of 400 births; most people are homozygous recessive for this trait. It is also a sensitive trait to investigate. It requires that students ask those surveyed if they were born with this condition. Most polydactyl individuals have had a surgical procedure to remove the extra digit.

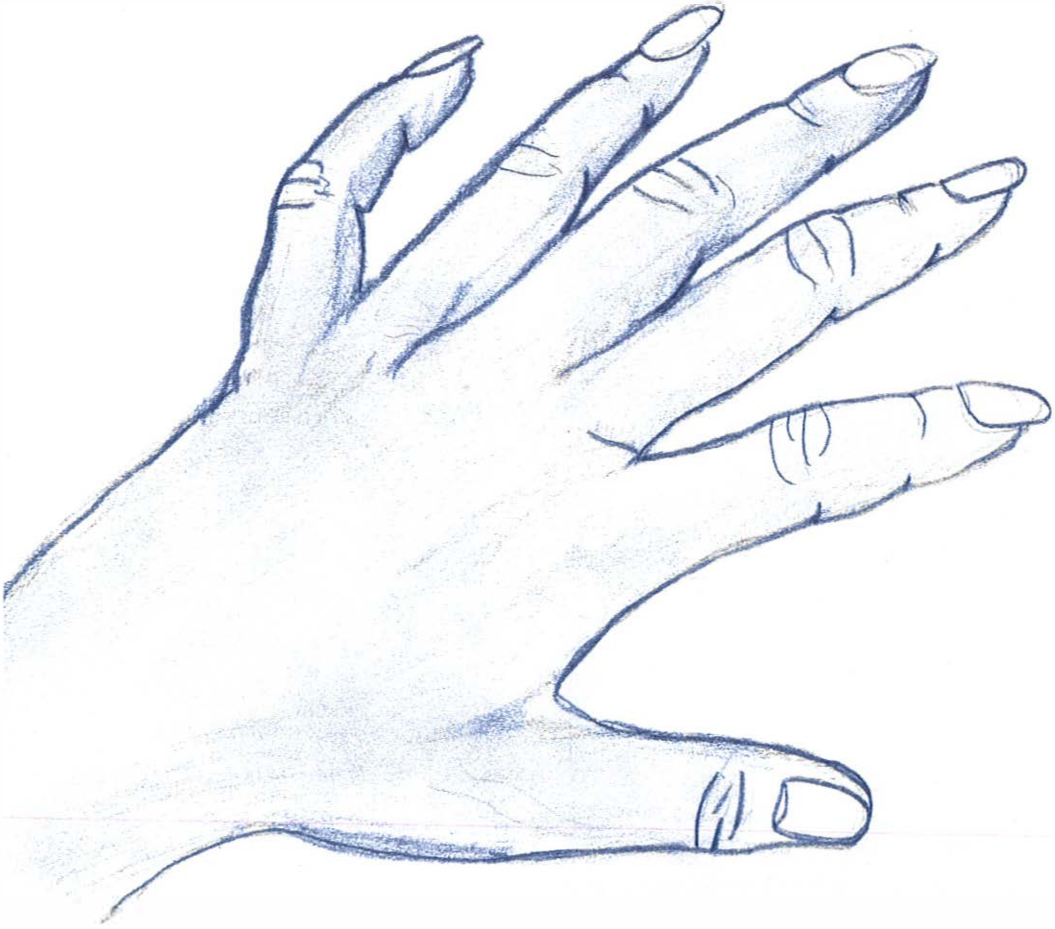


Figure 10.11. Drawing of a polydactyl hand

H. Index finger length (S/s)—measures the relative length of the index finger to the ring finger. This is considered a sex-influenced trait. The dominant allele in men produces a short index finger relative to the ring finger; in women, the dominant allele produces an index finger that is equal to or greater than the ring finger in length. Women need two short-finger alleles to produce the short-finger effect; men need just one short-finger allele to produce the effect. This gene is not likely to be found on the X chromosome; sex-influenced traits can be autosomal. This trait requires a simple "T" grid to determine the phenotype. **(See Figure 10.14,** Template for Measuring Index Finger Length Phenotype.) Pattern baldness is another example of a sex-influenced trait.

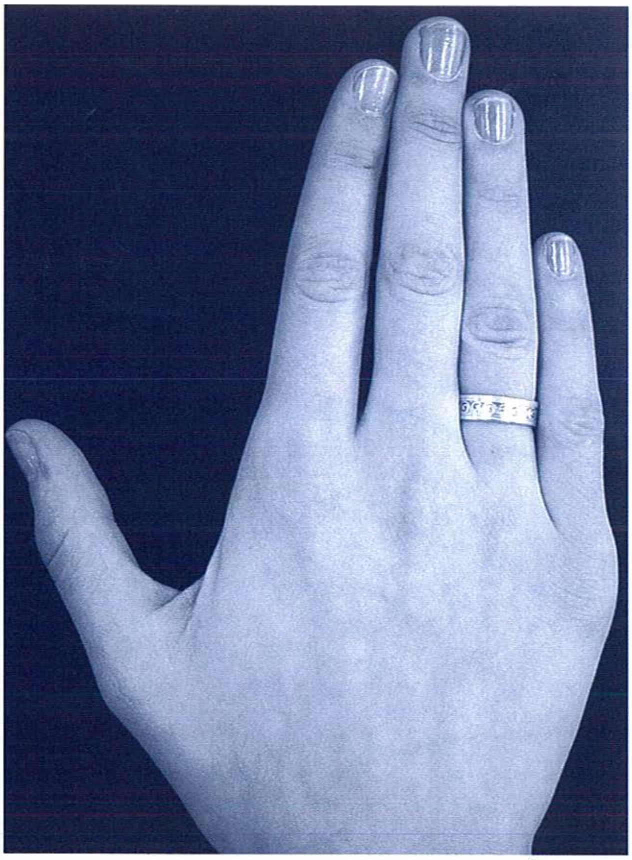


Figure 10.12. Index finger greater in length than ring finger

Figure 10.13. Index finger lesser in length than ring finger

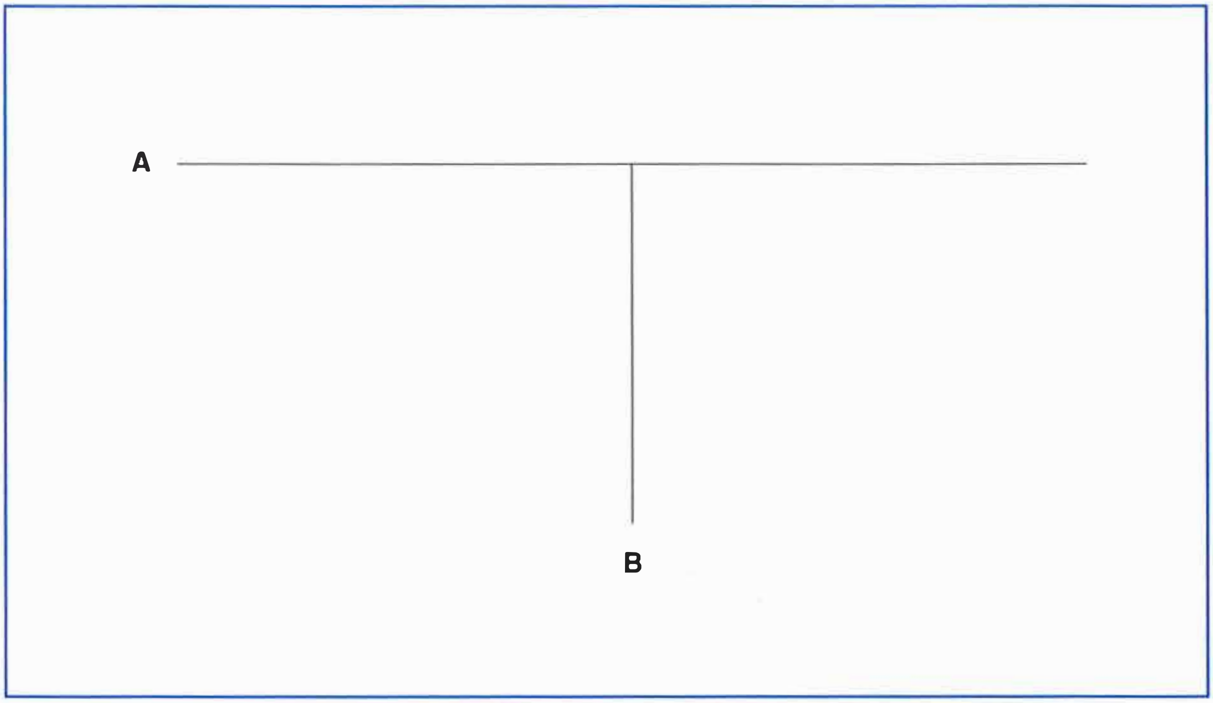


Figure 10.14. Template for measuring index finger length phenotype

Instructions: Lay right hand on this grid so that the middle finger lies on Line B and the tip of the ring finger is in line with Line A. If the index finger lies below Line A, then the phenotype is "short index finger." If the index finger lies on or above Line A, then the phenotype is "long index finger."

APPENDIX

Appendix A

Identifying and Using Learning Styles to Facilitate Instruction

by Nannette Smith,
DIVISION OF NATURAL, BEHAVIORAL, AND
SOCIAL SCIENCES, BENNETT COLLEGE

AT THE BEGINNING of the 2000 fall semester, faculty members at our college who taught introductory biology gathered to plan for coming classes. One professor who had attended a Project Kaleidoscope summer workshop boldly announced what many of us had come to suspect: "The emperor has no clothes," she said. "We are teaching but our students are not learning. We must change." And change we did.

The introductory biology professors decided that knowledge of how each student learned would help us as instructors and empower our students to direct changes in our pedagogical techniques. In pursuit of those goals, I designed the following cooperative venture. I began the process by telling my students about the conversation and events that had led to the need for change in the course structure. To teach them more effectively, I said, I needed their help. I went on to explain that each of them was a unique learner: They each had their own style of learning and their own learning experiences. To help them understand introductory biology, *I* would need to know about these learning styles and experiences. I challenged my students to accept and share responsibility for their own learning and "do science" at the same time. They accepted the challenge.

My first step was to educate both my students and myself about learning style theory. I used my course Web site at Blackboard.com to link to a site where each student would take the NC State Index of Learning Styles Questionnaire, www2.ncsu.edu/unity/lockers/users/f/felder/public/ILSdir/ilsweb.html,* online and free-of-charge. The site also provided us with two

(Reprinted, with permission, from *College Pathways to the Science Education Standards*, E. D. Siebert and W. J. McIntosh, eds. Arlington, VA: National Science Teacher's Association, 2001.)

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* [The updated URL is http://www.engr.ncsu.edu/learningstyles/ilsweb.html—Ed.]

articles that contained in-depth explanations of theories of learning styles and their practical applications. As the professor, I was responsible for providing copies of the articles. After reading the articles, each student formed a hypothesis as to what the inventory would show her or his learning style to be. Students then took the inventory and printed out two copies of their results. One copy was placed in each student's file; the other was kept by the student. When all students had completed the assignment, they brought the results to class. Each student presented her or his results to the class and compared the inventory results to her or his hypothesis. Much discussion ensued. Some agreed with the inventory results and some did not. The students drew up conclusions as to how they would alter note taking, classroom questioning, and study habits as a result of the inventory. Each student's hypothesis, process, results, and discussion were combined in a written report that was turned in to me. We also discussed the changes that I would have to make in my classroom presentation in order to support the learning styles of all students.

In the true spirit of scientific research we quantified our results. We compiled total class results using Microsoft Excel to create tables and graphs of our data. Students unfamiliar with Excel were responsible for arranging tutorials with me or with classmates. Numerous e-mails followed as students explored how to graph and what graphs were most illustrative of the data gathered. The resulting graphs were included in their written reports.

The introduction of learning style theory, the cooperative investigation, and the inventory results significantly altered the nature of student-professor interaction in my class. Whereas students had formerly asked me simply to repeat material or to provide further explanation when they were confused, now their requests became much more specific and helpful to me. Students now asked if they could be provided with graphics, models, or sequential explanations to help them understand a concept. Oftentimes they cited their learning styles as justifications for their requests. Additionally, students began to help their peers. More important to me were their suggestions as to how I might alter a learning experience in order to address the styles of classmates.

I was thrilled when non-biology majors and students from other colleges began to access my site to take the inventory. However, my greatest reward came when several of my students commented, "Why haven't we been told this before? Everyone needs to know this!" Now, one hopes, everyone will.

Appendix B

Biology Success! and The National Science Education Standards * (9–12)

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* National Research Council. 1996. *National Science Education Standards*. Washington, DC: National Academies Press.

	Inquiry			Ecology						Evolution			Cell Biology				Genetics		
STANDARDS	Developing Hypotheses	Designing Controlled Experiments	Graphing Data	Web of Life Activity	Analyzing Food Webs	Biogeochemical Cycles	Fast Plants	Pond Investigation I	Pond Investigation II	Science and Religion	Mussel Beach Simulation	Phylogenetic Trees	Cell Cycle Role-Play	The Cell Tour	Environmental Factors and Enzyme Activity	Egg Osmosis	Mendelian Genetics	Genetics on the WWW	Human Monogenic Traits
CONTENT STANDARD A: SCIENCE AS INQUIRY																			
A:1:1 Identify questions and concepts that guide scientific investigations.	X	X					X		X		X	X			X	X			X
A:1:2 Design and conduct scientific investigations.		X					X		X						X	X			X
A:1:3 Use technology and mathematics to improve investigations and communication.			X				X		X		X				X	X			X
A:1:4 Formulate and revise scientific explanation and models using logic and evidence.			X				X		X		X	X			X	X			X
A:1:5 Recognize and analyze alternative explanations and models.	X						X		X			X				X			
A:1:6 Communicate and defend a scientific argument.			X				X		X		X	X			X	X			X
A:2 Understandings about scientific inquiry.	X	X					X	X	X		X	X			X	X			X
CONTENT STANDARD C: LIFE SCIENCE																			
C:1:1 Cells have particular structures that underlie their functions.[1]													X	X		X			
C:1:2 Most cell functions involve chemical reactions.[1]															X				
C:1:6 Cells can differentiate.[1]													X						
C:2:1 The instructions for specifying the characteristics of the organism are carried in DNA.[2]																		X	
C:2:2 Most cells in a human contain two copies of each of 22 different chromosomes, and two copies of each gene.[2]																	X	X	X
C:2:3 Changes in DNA (mutations) occur spontaneously at low rates.[2]																		X	
C:3:1 Species evolve over time.[3]											X								
C:3:3 Natural selection and its evolutionary consequences provide a scientific explanation for the striking molecular similarities observed among the diverse species of living organisms.[3]												X							
C:3:4 The millions of different species of plants, animals, and microorganisms that live on earth today are related by descent from common ancestors.[3]											X	X							
C:4:1 The atoms and molecules on the earth cycle among the living and nonliving components of the biosphere.[4]						X													
C:4:2 Energy flows through ecosystems in one direction from photosynthetic organisms to herbivores to carnivores and decomposers.[4]				X	X														
C:4:3 Organisms both cooperate and compete in ecosystems.[4]								X	X										
C:5:6 As matter and energy flow through different levels of organization of living systems, chemical elements are combined in different ways.[5]						X													
CONTENT STANDARD D: EARTH AND SPACE SCIENCE																			
D:2:1 Each element on earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles.[6]						X													
CONTENT STANDARD G: HISTORY AND NATURE OF SCIENCE																			
G:2:1 Science distinguishes itself from other ways of knowing.[7]										X									
G:2:2 Scientific explanations must meet certain criteria.[7]										X									
G:2:3 All scientific knowledge is, in principle, subject to change as new										X	X	X							

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[1] C:1=The Cell; [2] C:2=The Molecular Basis of Heredity; [3] C:3=Biological Evolution; [4] C:4=The Interdependence of Organisms; [5] C:5=Matter, Energy, and Organization in Living Systems; [6] D:2=Geochemical Cycles; [7] G:2=The Nature of Scientific Knowledge

Appendix C

Student Handouts

Developing Hypotheses

Activator/Connector

Can all questions be addressed using the scientific method? What types of questions can be and what types can't be?

Activity Purpose

This activity is designed to help you to practice making observations about the natural world and to convert scientific questions based on those observations into hypotheses. You will also learn to differentiate between hypotheses that can and can't be tested using controlled experimentation.

General Background

The scientific method represents a systematic approach to formulating and answering questions about the natural world. The first steps of the scientific method include making an observation and developing a reasonable explanation for that observation in the form of a testable hypothesis.

Vocabulary

scientific method, observation, hypothesis

Learning Outcomes

After completing this activity, you will be able to:

Inquiry Skills

- Distinguish between questions that can and can't be addressed scientifically
- Develop alternative testable hypotheses to explain observations
- Apply key scientific inquiry vocabulary: *scientific method, observation, hypothesis*

Activity Sequence

1. Complete Part A on how to develop and state a hypothesis.

2. Complete Part B on how to develop alternative hypotheses based on observations you have made.

3. Determine which of the hypotheses in Parts A and B could be tested under controlled conditions, and justify your decisions (Part C).

4. Follow-up discussion questions

Procedure

Hypotheses are based on observations. A scientist observes or notices something about our natural world and wonders why it happens or how it works. The first step, then, in the scientific method is to clearly write down the *observation* about which you have questions (see the following examples). A *hypothesis* is a reasonable, scientifically testable explanation for an observation. Scientists formulate hypotheses in the form of statements rather than questions.

Complete the following exercises to practice developing hypotheses. The first set of exercises (Part A) asks you to develop hypotheses for observations provided to you. The second set of exercises (Part B) asks you to make your own observations and then formulate hypotheses. Remember that a hypothesis must be in statement form and must be able to be tested by an experiment. Finally, Part C asks you to decide which of the hypotheses you developed could be tested under controlled conditions.

Part A

For each of the following observations, list two alternative hypotheses (reasonable explanations for an observation—see examples) in the spaces provided.

Observation 1: Sunflowers growing in Judy's front yard are shorter than the sunflowers growing in her backyard.

Hypothesis: Salt from the road has washed into the front garden and stunted the growth of those sunflowers.

Hypothesis:

Hypothesis:

Observation 2: Cigarette smokers have more colds.

Hypothesis: Cigarette smokers touch their fingers to their mouths more frequently, increasing their contact with the cold virus.

Hypothesis:

Hypothesis:

Part B

In the spaces below, write your own observations and provide two alternative hypotheses for each.

Observation 1:

Hypothesis:

Hypothesis:

Observation 2:

Hypothesis:

Hypothesis:

Part C

A *controlled experiment* is one in which a control group is compared in some way to an experimental group to determine the presence of cause and effect. For example, if an investigator wanted to conduct a controlled experiment to test whether road salt inhibited plant growth, he or she might compare the growth rates of salt-treated plants to the growth rates of untreated (control) plants.

Not all scientific hypotheses can be tested under controlled conditions. Certain hypotheses concerning the origin or age of the universe, for example, cannot be tested by direct comparison of our universe with another "control" universe. (This doesn't mean, however, that there isn't a great deal of valid scientific research resulting in testable hypotheses addressing questions about the universe.)

Put an asterisk (*) next to those hypotheses you developed in Parts A and B that could be tested using controlled experiments. Be prepared to justify your choices.

Follow-up Discussion Questions

Review:

1. What are the main concepts you have learned from this activity?

Interpretive:

2. After sharing your answers with peers, did you find that any of your hypotheses could not be tested scientifically? Were there any that could not be tested under controlled conditions? How did you decide?

Reflective:

3. Do you feel better able to formulate and identify a testable hypothesis?

4. What aspect of this activity most contributed to your learning?

Designing Controlled Experiments

Activator/Connector

Not all fields of science arrive at conclusions through the process of controlled experimentation. Can you think of some examples of fields that do and fields that do not?

Activity Purpose

This activity is designed to help you to practice some of the basic steps of the scientific method by designing a controlled experiment to test a hypothesis.

General Background

The scientific method represents a systematic approach to formulating and answering questions about the natural world. Experiments are designed to answer questions by investigating cause and effect relationships in nature. Many, but certainly not all, scientific investigations are carried out under controlled conditions.

Vocabulary

scientific method, hypothesis, experiment, experimental procedure, independent variable, treatment, dependent variable, experimental control, prediction

Learning Outcomes

After completing this activity, you will be able to:

Inquiry Skills

- Design controlled experiments to test hypotheses
- Apply key scientific inquiry vocabulary: *independent variable, experimental control,* etc. (see Vocabulary list)

Activity Sequence

1. For each part (A through G), read the example provided and record your answers to the questions on the handout Worksheet for Designing Controlled Experiments.

2. Complete each part before moving to the next.

3. Follow-up discussion questions

Procedure

Designing an experiment involves writing a step-by-step list, called an *experimental procedure*, to test the hypothesis. You will need to consider all of the following when designing your procedure:

- Treatment—the variable you want to test the effect of
- Treatment levels
- How you will measure the effect of the treatment
- Experimental control
- Other variables that must be held constant to test the effect of the treatment

As you progress through the descriptions of these important design components of a scientific experiment, you can begin to construct your own experiment based on a hypothesis.

Part A: Choosing the Treatment (the Independent Variable)

One of the most important considerations in designing an experiment is choosing the *treatment* (also called the *independent variable*). This is the one variable or factor that, when changed by a scientist, best helps to answer an experimental question and test a hypothesis. Follow the example below to learn how to identify the treatment or independent variable.

EXAMPLE:

Hypothesis: Road salt stunts the growth of sunflowers.

Put another way, we want to test the effect of road salt on sunflower growth. In order to test this hypothesis, we will probably change the amount of road salt and determine the effect on sunflower growth. Since we will be testing the effect of road salt and changing its levels, then the independent variable in this case is road salt.

Independent variable: Amount of road salt

Scientists also provide a rationale for why their hypothesis is valid and worth testing, based on prior knowledge.

Rationale: Pine trees located near salted road surfaces tend to have more brown needles than trees located farther away. If salt damages pine trees, it is logical to assume that it may damage another plant, like the sunflower, as well.

In the spaces provided on your worksheet,

- write out the hypothesis you will be testing,
- identify the independent variable (treatment) to be changed, and
- provide a rationale for your hypothesis.

Part B: Choosing the Treatment Levels

You will often need to do some further literature review to determine the specific range of *treatment levels* for your experiment. For example, you don't want to expose the sunflowers to huge amounts of road salt—levels well beyond those ever found at roadsides. This may result in ALL of the plants dying, and you'll never get a chance to see whether growth is stunted. Typically, two or three levels of a treatment represent a good starting point for an experiment.

EXAMPLE:

After researching the amount of salt typically found at roadsides, the following treatment levels were decided upon:

Treatment levels: 0.5 grams, 1.0 grams, and 1.5 grams of road salt

In the space on your worksheet, list the treatment levels you will use in your experiment.

Part C: Identifying the Dependent Variable

The variable that is measured in an experiment is called the *dependent variable*. The typical experiment is designed to test the effect of the independent variable on the dependent variable. After identifying the dependent variable in an experiment, you will then have to decide how to measure it.

EXAMPLE:

To test the effect of road salt (our independent variable) on sunflower growth, we will have to measure sunflower growth.

Dependent variable: Sunflower growth

Now we have to decide *how* to measure sunflower growth. There is more than one way to measure growth. We could, for example, measure the heights of the sunflower plants. Or, we could measure the biomass of each plant by cutting the plants at soil level and weighing them.

Units of measurement for dependent variable: Height in centimeters

In the spaces provided on your worksheet, list

- the dependent variable for your experiment, and
- the units of measurement for your dependent variable.

Part D: Identifying the Experimental Control

Experiments should also include what is called an *experimental control*. The experimental control provides a reference point for comparison and indicates that all other aspects of the experiment are working. The typical experimental control is to eliminate the treatment (the independent variable) you are testing altogether.

EXAMPLE:

Experimental control: No road salt (or 0 grams of road salt)

In the space provided on your worksheet, identify the experimental control.

Part E: Identifying Other Variables to Hold Constant

In experiments, there are *other variables that must be held constant* so that we can isolate the effect of the independent variable.

EXAMPLE:

Other variables to hold constant: Variety of sunflower studied, amount of light, amount of water, temperature, type of road salt, etc.

In the space provided on your worksheet, list other variables that you will have to hold constant in order to isolate the effect of your independent variable.

Part F: Designing the Experimental Procedure

The experimental procedure is the step-by-step outline of how you will carry out your experiment.

EXAMPLE:

Experimental procedure

1. Plant sunflower seeds. Water and keep warm.

2. Once seeds have germinated, place seedlings under grow-light and water daily.

3. Divide 7-day-old seedlings into 4 groups of 10 plants each, all of equal starting height. The groups are 0 salt (experimental control), 0.5 g salt, 1.0 g salt, and 1.5 g salt.

4. Sprinkle soil surface with salt treatments.

5. Record plant heights in centimeters at 14 days.

6. Determine average plant heights for each group.

In the space provided in your handout, list the step-by-step experimental procedure you will follow.

Part G: Predicting the Outcome of the Experiment

Once the experimental procedure has been developed, a *prediction* of the outcome of the experiment can be made. The prediction can be more general in nature or more specific.

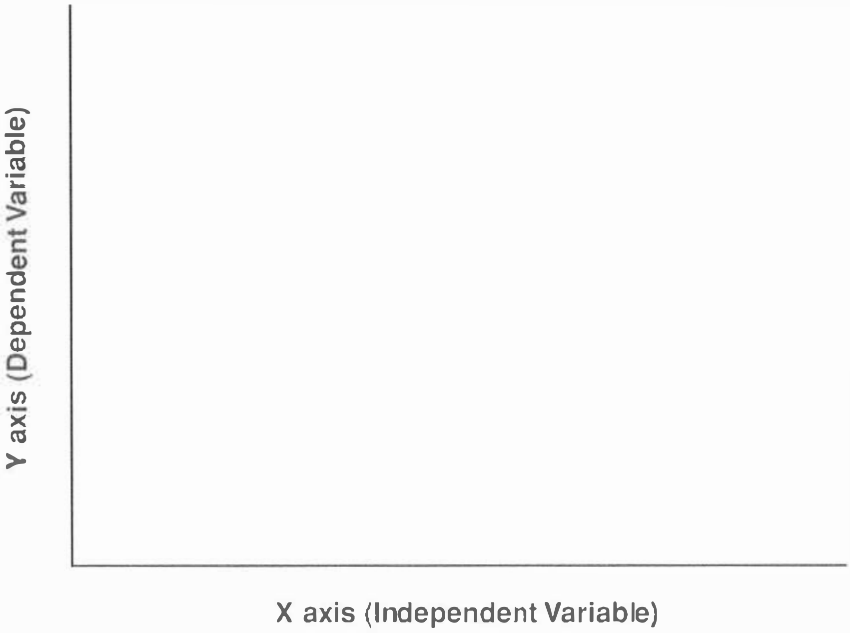
EXAMPLE:

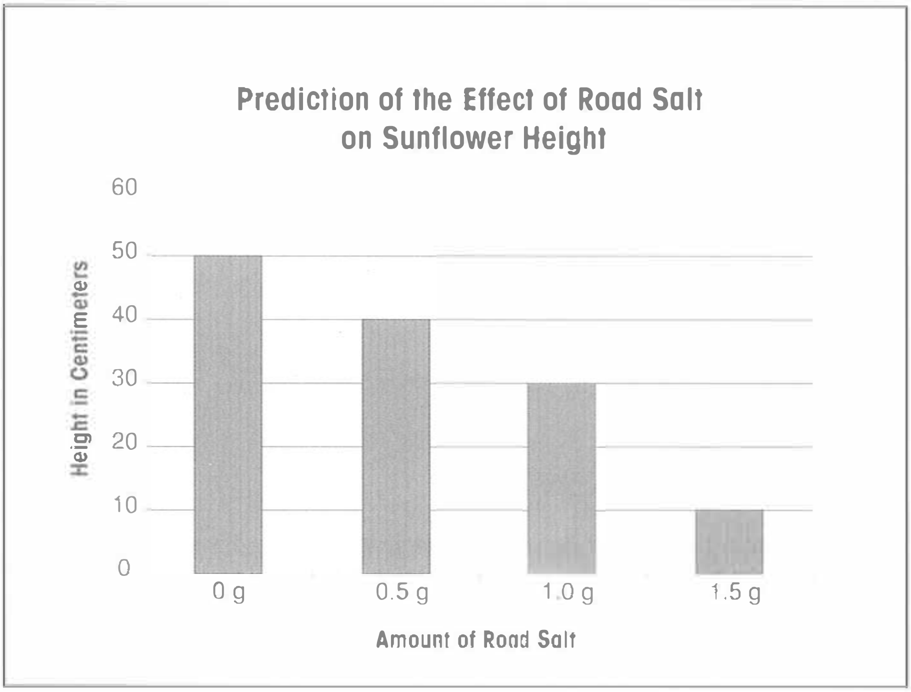
General Prediction: As salt levels increase, sunflower plant heights will decrease.

Specific Prediction: After 14 days, the 1.5 g salt group will be shortest in height, the control group will be tallest, and the 0.5 g and 1.0 g groups will have intermediate heights.

You may also find it helpful to depict your prediction in the form of a graph. The dependent variable goes on the Y, or vertical, axis, while the independent variable is typically placed on the X, or horizontal, axis.

EXAMPLE:





In the spaces provided on your worksheet,

- write your prediction for the outcome of your experiment in the form of a statement; and
- sketch a graphic representation of the predicted outcome and label the axes.

Follow-up Discussion Questions

Review:

1. In an experiment, distinguish between an independent variable, a dependent variable, and a variable that must be held constant.

Interpretive:

2. In the spaces below, give an example of a scientific hypothesis that can be tested under controlled conditions and an example of one that can't.

Hypothesis that can be tested under controlled conditions:

Hypothesis that can't be tested under controlled conditions:

3. Sarah designed an experiment to test whether the length of time spent washing hands reduces the frequency of colds. She asked some students to wash their hands for 30 seconds, some for 60 seconds, and a third group for 90 seconds. What is the independent variable for this experiment? the dependent variable? Provide a minimum of two variables that should be held constant. Provide an experimental control for the experiment.

Independent variable:

Dependent variable:

Two examples of other variables to hold constant:

Experimental control:

4. Design another experiment based on a different hypothesis. Or, using the same hypothesis, develop an alternative experiment to test it.

Reflective:

5. Describe the aspect of this activity that most contributed to your understanding of the scientific method. In addition, describe those aspects of the scientific method you found to be most challenging.

WORKSHEET FOR
DESIGNING CONTROLLED EXPERIMENTS

Name: ______________________

Hypothesis →

Independent Variable (Treatment) →

Rationale for Hypothesis →

Treatment Levels →

Dependent Variable →

Units of Measurement for Dependent Variable →

Experimental Control →

Variables That Must Be Held Constant →

Experimental Procedure →

Predicted Outcome
(Written Form)

Predicted Outcome
(Graphic Form)

Graphing Data

Activator/Connector

Have you heard the expression “A picture is worth a thousand words”? From your perspective, is that statement true? Discuss some of the advantages of depicting information, including scientific data, in graphic form.

Activity Purpose

This activity is designed to help you practice some of the basic steps for converting data obtained from an experiment to graphic form.

General Background

Graphs often provide the most efficient way to observe and communicate any major trends in the data collected during a scientific experiment. Knowing how to construct graphs also makes it easier to interpret information presented to you in graphic form.

Vocabulary

graph, figure, independent variable, dependent variable, axis, X and Y axes, scale, caption

Learning Outcomes

After completing this activity, you will be able to:

Inquiry Skills

- Orient the independent and dependent variables to their respective axes
- Choose an appropriate format for a graph (line or bar)
- Choose appropriate scales for the X and Y axes
- Plot data points on a graph
- Write descriptive titles for a graph
- State observed trends in written form

Activity Sequence

This activity is divided into six main parts (A through F), plus follow-up discussion questions and applications:

Part A: Identifying the independent and dependent variables
Part B: Graphing the independent and dependent variables
Part C: Choosing between the bar and the line graph
Part D: Choosing scales for the axes
Part E: Writing figure titles and stating trends
Part F: Checking the graph with a checklist

Procedure

Part A: Identifying the Independent and Dependent Variables

In order to place the variables from an experiment on their proper axes when constructing a graph, you must first be able to distinguish the independent from the dependent variable.

The *independent variable* in an experiment is the variable that you manipulate. It represents the treatment that you've chosen to investigate. The *dependent variable* is the variable that you measure. Therefore, in the typical experiment, you are trying to determine the effect that the independent variable has on the dependent variable.

In the following exercises, experiments are described and you are asked to identify the independent and dependent variables. Write your answers on the Graphing Data Worksheets, Part A. An example follows.

EXAMPLE:

David designed an experiment to determine whether the number of offspring produced by bobcats in the spring was affected by winter rodent density.

Independent variable: rodent density in winter

Dependent variable: number of bobcat offspring

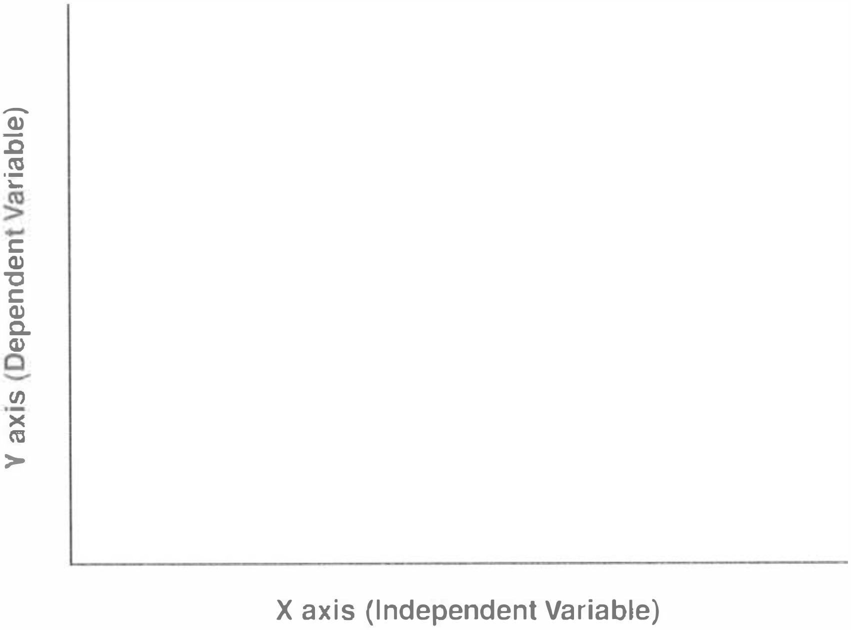
1. A group of researchers at the National Cancer Institute conducted a study to determine whether the incidence of liver cancer was affected by the level of alcohol consumption.

2. A high school teacher decides to investigate whether students who study prior to an exam get better grades on the exam.

3. That same high school teacher decides to investigate whether students who study prior to an exam take less time to finish the exam.

Part B: Graphing the Independent and Dependent Variables

Once you feel confident that you can distinguish between the independent and dependent variables in an experiment, it's easy to match each variable with its proper axis on a graph. The *X axis* (see the following diagram) is the horizontal axis, also known as the *independent axis*, because the range of data points representing the independent variable is located here. The range of data points representing the dependent variable (the variable we measure) is located on the vertical or *Y axis*, also called the *dependent axis*.

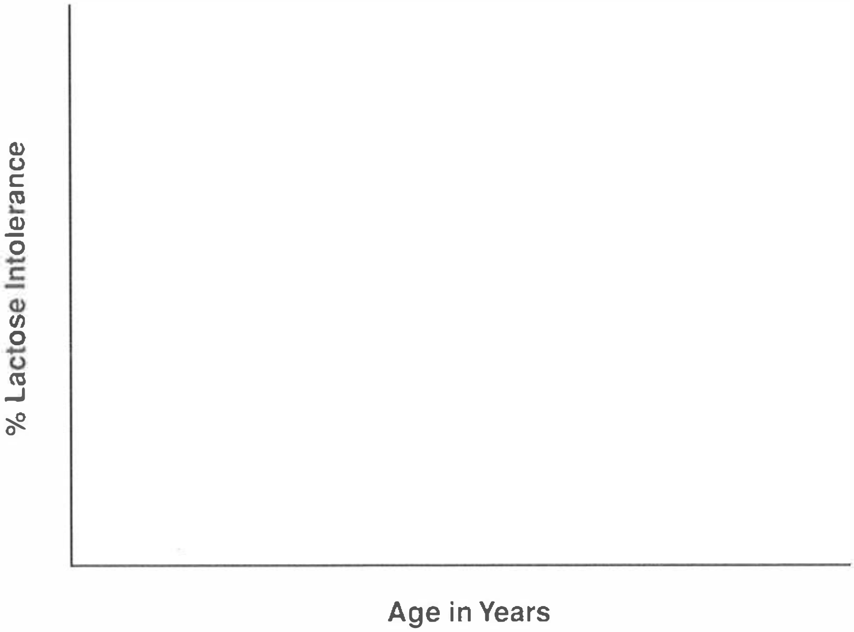


It is also important to include the units of measurement for the independent and dependent variables where appropriate. For example, was the age of the organism measured in years or in months? If the dependent variable was weight gained, was weight measured using grams or kilograms?

In the following exercises, experiments are described. You are asked to identify and correctly orient the independent and dependent variables to the appropriate axis on the Graphing Data Worksheets, Part B. An example follows.

EXAMPLE:

A medical researcher investigated whether the percentage of the population with lactose intolerance increases with age.



1. For her class research project, Sara studied whether different levels (in millimolar, or mM) of the hormone ecdysone affected the molting rate (number of molts/year) in crayfish.

2. At a nearby agricultural college, scientists are investigating whether increased temperatures (in °C) due to global warming result in decreased apple production.

Part C: Choosing between the Bar and the Line Graph

A *line graph* is created when you plot data points and connect them together with lines to see how much the values change from point to point. How do you decide whether your data points should be connected by lines (as in a line graph) or represented as separate columns (as in a bar graph)?

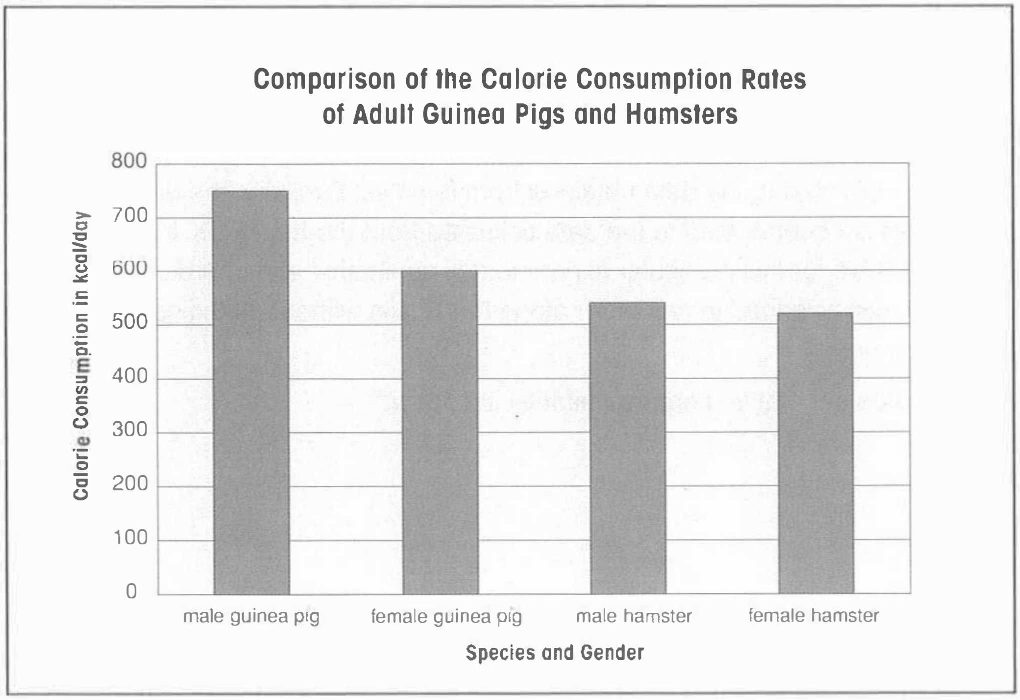
One helpful way to assess which type is appropriate for your data set is to first classify your independent and dependent variables as either qualitative or quantitative. *Qualitative* variables may be represented by categories or types, and the data aren't ordered. Examples of qualitative variables in an experiment might be gender (male or female) or type of compound tested (arsenic, lead, cadmium, or zinc).

The data set representing a *quantitative* variable has a scale of measurement that is ordered with respect to magnitude. Examples of a quantitative variable could be time measured in number of days or weight gain measured in grams.

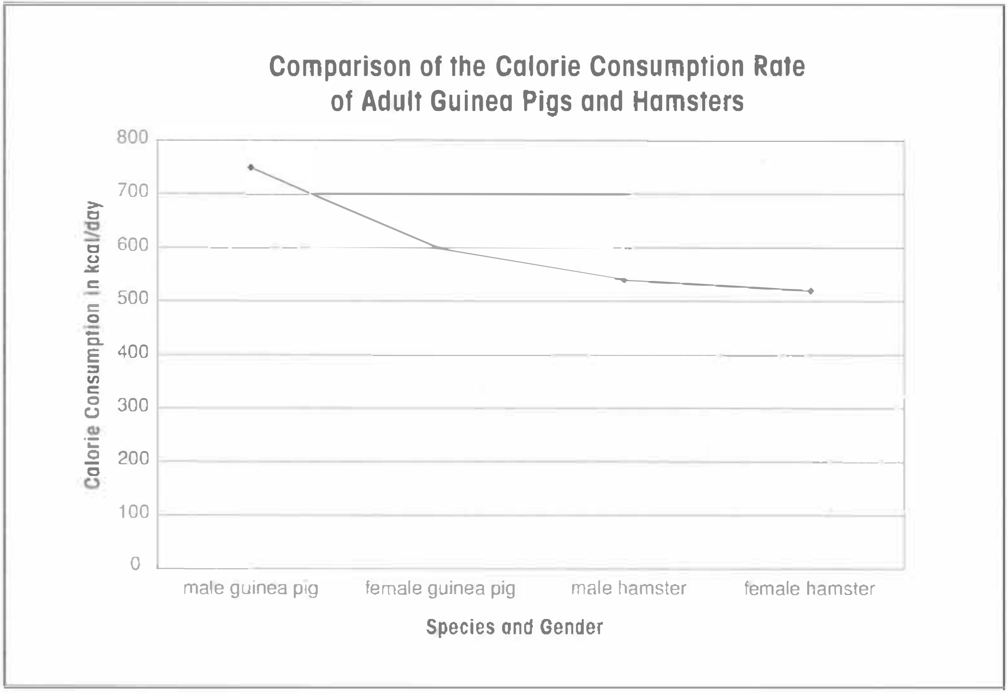
Qualitative data are discrete; that is, they are separate from each other and often unrelated. For this reason, a bar graph would be the best type for representing qualitative data, because if the data aren't related to each other by scale, then we shouldn't be connecting the data points with lines. The following example should help to illustrate this point. In this example, the same data set is plotted both as a bar graph and as a line graph for comparison.

EXAMPLE:

Qualitative Data: Celia conducted a study which compared the calorie consumption of adult guinea pigs and adult hamsters. She found that, on average, female guinea pigs consumed 600 kcal/day, while male guinea pigs consumed 750 kcal/day. In hamsters, she found that males consumed 540 kcal/day and females consumed 520 kcal/day. Here are Celia's data plotted as a bar graph:



Here are Celia's data plotted as a line graph:

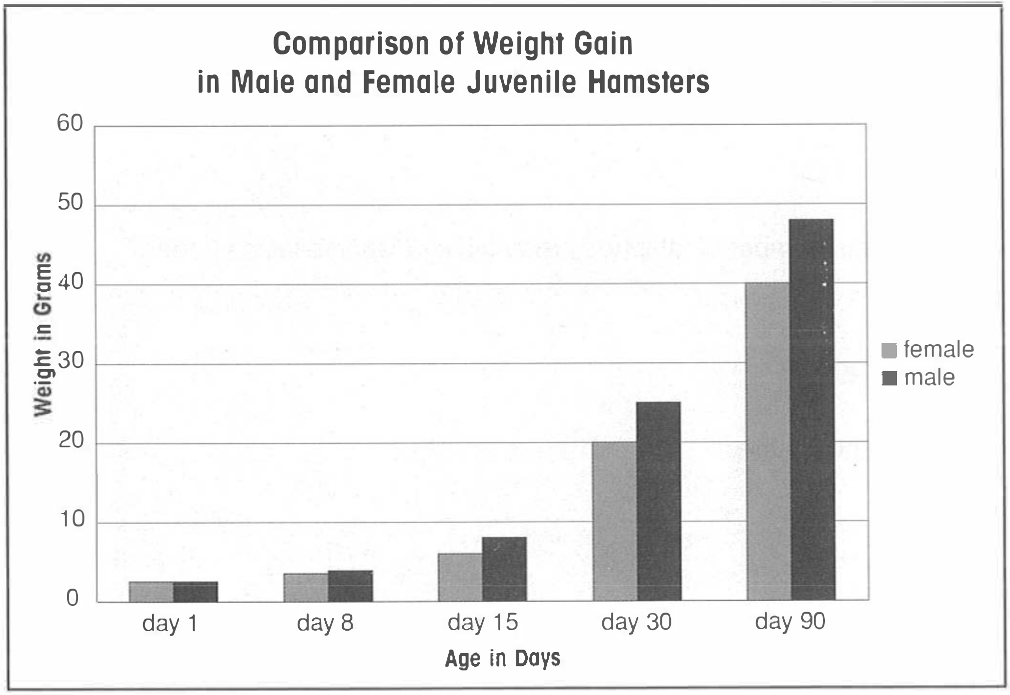


As you can see, using lines to connect the data points doesn't make sense, because the data obtained from males is unrelated to the data obtained from females. Similarly, the data collected from the guinea pigs is unconnected to the data collected from the hamsters. In addition, the independent variable for this particular experiment is qualitative and unordered; that is, the data could have been arranged in any order along the X axis without changing the ability to see the differences.

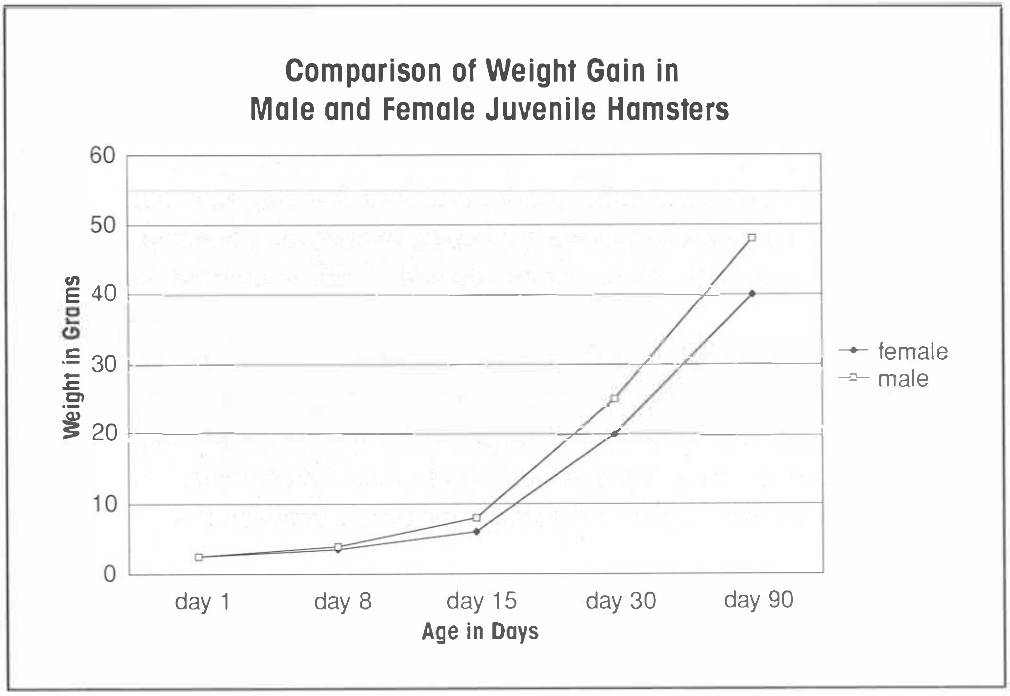
Following is a graph of a data set that is more quantitative in nature.

EXAMPLE:

Quantitative Data: Jon wanted to compare weight gain in juvenile male and female hamsters over their first three months of life. During that period, he weighed the hamsters five times. Here are Jon's data graphed as a bar graph:



Here are Jon's data graphed as a line graph:



While it is possible to see the differences in weights between males and females in both graphs, it is much easier to observe the overall shape and trends in the growth curve over the 90-day period by viewing the line graph. It shows us immediately that the rate of growth was quite rapid for both male and female hamsters during the first 20 days of life, and that after 20 days, the growth rate tapered off somewhat. In this case, the line graph makes the information more accessible.

In the following exercises, name the independent variable, determine whether it is qualitative or quantitative, and decide whether the line graph or the bar graph is more appropriate. Record your answers on the Graphing Data Worksheets, Part C. An example follows.

EXAMPLE:

Amy counted and compared the number of offspring produced by *Daphnia* raised under light and dark conditions.

Independent variable? light or dark

Qualitative or quantitative? qualitative

Bar or line graph? bar

1. Mike counted the number of bacterial colonies on agar plates containing 1, 2, 5, 10, and 100 mM of the antibiotic tetracycline.

2. Amos studied whether differences in the population density of bobcats among several areas in northern Vermont had an impact on the snowshoe hare population numbers in those areas.

3. Allison wanted to determine whether the population density of robins was greater in urban, suburban, or rural areas of southern New Hampshire.

Part D: Choosing Scales for the Axes

A graph is a pictorial representation of a data set. If that picture is distorted, it may be difficult to make an accurate interpretation of the relationships we are hoping to uncover. Choosing the appropriate scale for the X and Y axes makes it easier for you and others to interpret any trends in the data.

You'll need to develop a scale for any of the variables that are quantitative. This could be both the independent and dependent variables if you are constructing a line graph or just the dependent variable in a bar graph. How do you determine the appropriate scale for your data set? The first step is to assess the overall range of the values a given data set contains. What is the lowest value? What is the highest value? What is the difference between the lowest and the highest value?

If the scale representing the data range for your variable is too small in scope, it may exaggerate minor differences. On the other hand, if the scale is too large for your data set, any differences will be hard to see. Moreover, it's aesthetically appealing to other observers when the overall scale of your graph uses the majority of the space provided. If you have been given a page-size piece of graph paper for constructing your graph, use the entire page so your graph is easy to view.

When constructing a line graph, if the independent variable covers a greater range of values than the dependent variable, then you will want to orient the graph paper so that the X axis is placed on the longer side of the paper. Next, you will want to determine how many squares you have available to use for each of your variables by counting the squares on your graph paper.

Divide the data range for each variable by the number of squares, as a rough estimate of what each square might represent numerically. Then you can make adjustments so that your squares represent units that are easy to interpret. Now you are ready to plot your data points. The examples below should to help illustrate this process.

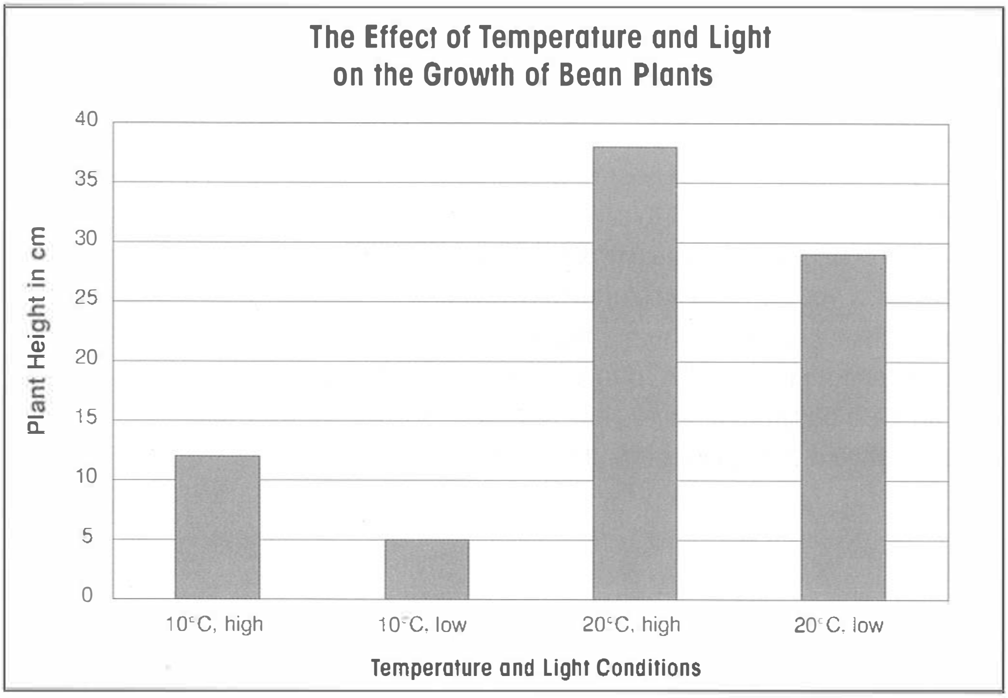
EXAMPLE:

Teresa measured the heights of several bean plants that had been grown under different conditions. Her data set is shown in the following table:

Condition	Average plant height in cm
10° C, high light	12
10° C, low light	5
20° C, high light	38
20° C, low light	29

Teresa's data range from 5 to 38 cm, a difference of 33 cm. She decides to orient "plant height in cm" on the shorter side of the graph paper. There are about 20 squares available on this axis (the Y axis in this case, since plant height is the dependent variable). But 33 cm divided by 20 squares is 1.65 cm/square. It would be very frustrating to try to construct or interpret a graph using such a scale. However, Teresa could have each square represent 2 cm and still be using much of the available space.

Teresa decides to have each square on the Y axis represent 2 cm. She doesn't label every square; instead she indicates where 10, 20, 30, and 40 cm occur on the Y axis. This provides enough information for anyone viewing the graph without making the axis too cluttered. Her final product follows.



For the following data sets, determine an appropriate scale for all *quantitative* variables by following the steps on the Graphing Data Worksheets, Part D. Your instructor has provided you with graph paper that is roughly 30 squares by 20 squares, so that you can plot the data on graphs constructed according to the axis scales you developed. (Remember that you can turn the graph paper so that the independent variable can be on the longer or shorter axis.) Record your answers on the worksheet.

1. Andre measured the oxygen production of different concentrations of a single-cell algae species.

Algae Concentrations in Cells/ml	Oxygen Production in mg O_2/L
0 (control)	1.1
600	1.3
800	1.5
1000	2.0
1600	2.9

2. May sampled the density of oak trees on four different plots bordering Lake Schuyler.

Plot Number	Number of Oak Trees/Hectare
A	453
B	209
C	517
D	444

Part E: Writing Figure Titles and Stating Trends

Now that you have chosen the proper graph type to illustrate your data, used appropriate scales for the axes, plotted your data, and labeled your axes with both the names of the variables and their units of measurement, there are a few more additions to make to the final product before incorporating your graph into a report.

Writing Figure Titles. In a report, a graph is often referred to as a *figure*. The graph will need a descriptive title, sometimes referred to as a *caption.* Let's take another look at our example study from Part D.

EXAMPLE:

If you recall, Teresa measured the heights of several bean plants that had been grown under different light and temperature conditions. She chose the title "The Effect of Temperature and Light on the Growth of Bean Plants," a title that really gives you an idea of the nature of her study. Titles such as "The Heights of Bean Plants," "Temperature and Light Effects," or even "Height vs. Temperature and Light" are less informative about the purpose of the study. The title does NOT have to be a complete sentence, but it should help orient the viewer to the displayed data.

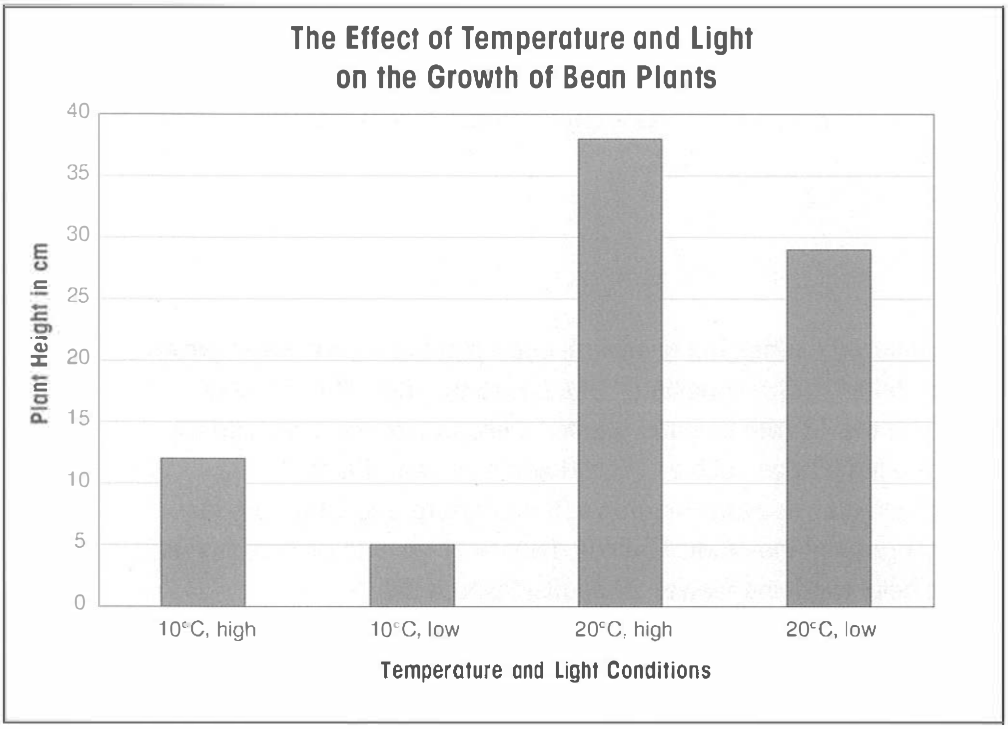
Write descriptive figure titles in the spaces provided for the two figures on the Graphing Data Worksheets, Part E.

Stating Trends. Rarely do we present a graph without some sort of accompanying text. For instance, in the typical scientific lab report, graphic representations of the experimental data would be included under the Results section. Any general trends observed by examining the graphs would also be noted within the text of the Results section. (Remember, *interpretation* of data—explanations of observed trends—is NOT included in the Results section of a scientific report. Instead, we state in written format any general or major trends observed in graphs.) Stating trends can help readers notice important aspects of your graph that they may have overlooked at first glance. It is also important for scientists to be fluent at converting visual information to written form and vice versa.

Let's go back once again to Teresa's study on the effect of temperature and light on bean plant growth.

EXAMPLE:

The graph of Teresa's data follows.



There a couple of trends we could state for this data set. For instance, we could point out the conditions for the lowest and highest observed heights. "The shortest heights were observed in bean plants kept under low light levels at 10°C, while the tallest heights were observed in bean plants kept under high light conditions at 20°C."

We could also state the separate effects of temperature and light on bean plant height. "Bean plants grown under high light conditions were taller than bean plants grown under low light levels. Similarly, bean plants grown under the higher temperature were taller than those grown under the lower temperature." As you see, none of these statements provide any explanation for why Teresa observed what she did; they simply restate the trends evident from viewing the graph.

In the spaces provided on the Graphing Data Worksheets, Part E, state any major trends you observe after viewing the two graphs on the worksheet.

Part F: A Final Checklist

Before submitting your graph for assessment, take the time to check it over to make sure it addresses the following aspects of graph making:

1. Are the independent and dependent variables oriented to the proper axes?

2. Are the axes labeled with the names of the variable and the units of measurement?

3. Does the graph occupy a majority of the available space?

4. Is the scale of each axis noted?

5. Is the scale labeled at major intervals only (and not every square)?

6. Does the graph have a descriptive title?

If you answered yes to all of the above, then you have acquired the basic skills needed to construct a simple line or bar graph for your next lab report. Congratulations!

Follow-up Discussion Questions:

Review:

1. Using the graph paper provided by your instructor, construct a complete graph for the following two studies.

a. Tara designed a study to investigate the relationship between tree trunk diameter and canopy height on a nearby forest plot. Here are her findings:

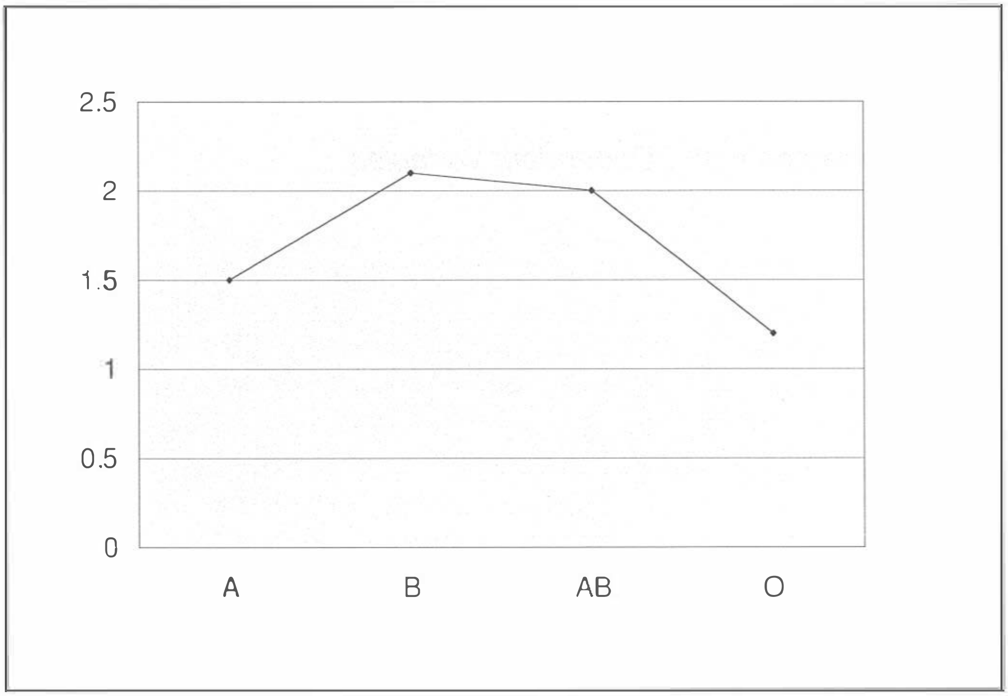
Canopy Height	Average Trunk Diameter in cm
15 meters	158
10–15 m	121
5–10 m	73
0–5 m	32

b. Drew hypothesized that male peacocks with longer tail feathers would spend more time displaying their tails to females than males with shorter feathers. He exposed five males that differed from each other in the length of their tail feathers to a female, and measured the total amount of time they spent displaying out of a 120-minute period. Here are Drew's data:

Length of Longest Tail Feather in cm	Time Spent Displaying in min
53	23
61	28
59	27
80	67
73	61

Interpretive:

2. Allyson constructed a graph based on the results of her study. She investigated the relationship between blood type and the incidence of flu in humans. For her study, she surveyed five people for each of the four blood types to determine how many incidents of flu they had suffered over the past 24 months. Her graph follows. Has she made any errors in construction? Explain.



3. Correct Allyson's mistakes by constructing a new graph based on her data, which follows.

Blood Type	Average Number of Flu Incidents (Over Past 24 Months)
A	1.5
B	2.1
AB	2.0
O	1.2

Reflective:

4. Identify the most difficult aspects of graphing from your perspective. Were you able to develop any strategies that you could share with other students?

5. Do you find it easier to interpret graphs constructed by others now that you understand how graphs are constructed?

GRAPHING DATA WORKSHEETS

Part A: Identifying the Independent and Dependent Variables

1. Independent variable:

Dependent variable:

2. Independent variable:

Dependent variable:

3. Independent variable:

Dependent variable:

GRAPHING DATA WORKSHEETS

Part B: Graphing the Independent and Dependent Variables

1.

2.

GRAPHING DATA WORKSHEETS

Part C: Choosing between Bar and Line Graphs

1. Independent Variable ______________________________

Circle Answers: Qualitative or Quantitative Bar Graph or Line Graph

2. Independent Variable ______________________________

Circle Answers: Qualitative or Quantitative Bar Graph or Line Graph

3. Independent Variable ______________________________

Circle Answers: Qualitative or Quantitative Bar Graph or Line Graph

GRAPHING DATA WORKSHEETS

Part D: Choosing Scales for the Axes

1. Independent variable ______________________________ Quantitative? __________

Data range ______________________________ Circle one: 20 or 30 squares

Scale: Each square = ______________________________ (include units)

Dependent variable ______________________________ Quantitative? __________

Data range ______________________________ Circle one: 20 or 30 squares

Scale: Each square = ______________________________ (include units)

2. Independent variable ______________________________ Quantitative? __________

Data range ______________________________ Circle one: 20 or 30 squares

Scale: Each square = ______________________________ (include units)

Dependent variable ______________________________ Quantitative? __________

Data range ______________________________ Circle one: 20 or 30 squares

Scale: each square = ______________________________ (include units)

GRAPHING DATA WORKSHEETS

Part E: Writing Figure Titles and Stating Trends

1. Sari designed a study to determine whether temperature influenced the number of eggs laid by female fruit flies. She counted the number of eggs produced by females kept at temperatures ranging from 5°C to 30°C. A graph of her data is shown below.

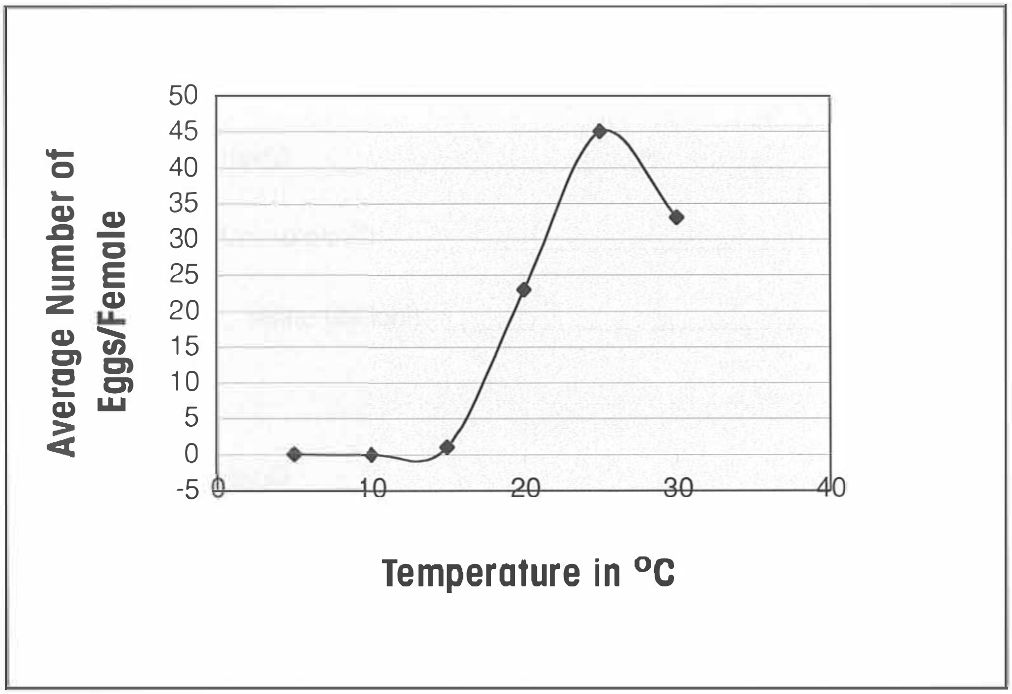


Figure Title:

State Trend(s):

2. To test his hypothesis that the number of dams on a river affects the number of spawning fish, Klaus sampled the numbers of spawning fish in several tributaries of the Cold River that differ in the number of dams. A graph of his findings is shown below.

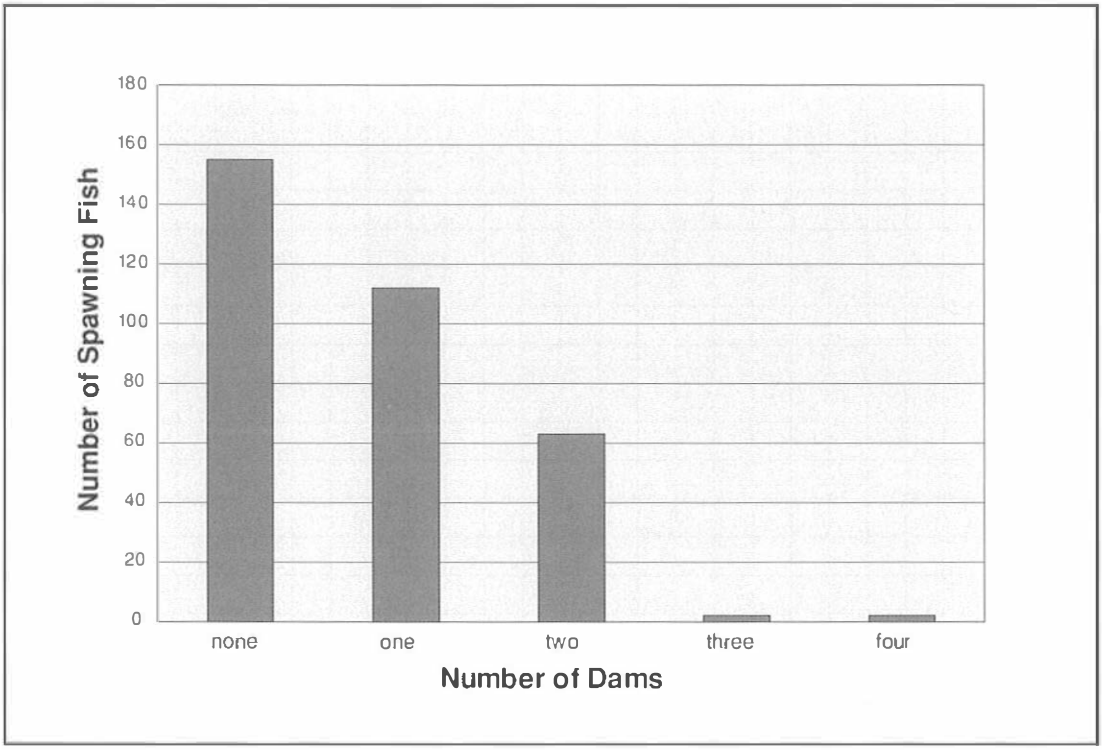


Figure Title:

State Trend(s):

Name: ______________________________

Title: ______________________________

Web of Life

Activator/Connector

Where do you fit in the web of life?

Activity Purpose

In this activity, your goal is to create a personal food web, based on a recent meal, in order to understand some basic food web concepts.

General Background

In order to survive, an organism must have a source of energy. Many organisms, including ourselves, obtain energy through eating. The web of life is the idea that all forms of life, including humans, are connected in a way that allows energy to flow through ecosystems.

Vocabulary

producer, primary consumer, secondary consumer, tertiary consumer, herbivore, omnivore, carnivore, decomposer, autotroph, heterotroph

Learning Outcomes

After completing this activity, you will be able to:

Content

- Construct a food web diagram that correctly links humans to other living organisms
- Define the terms listed under Vocabulary
- Apply these terms to a food web diagram

Materials

- Newsprint (1 sheet)
- Notebook paper
- Markers (5 different colors)

Activity Sequence

1. Record what you had for dinner last night, or a comparable amount of food.

2. Break down to the level of plants the components of the foods and drinks you had for dinner.

3. Asssemble your food web.

4. Label the food web with food web terminology.

5. Follow-up discussion questions

Procedure

☐ 1. From the list of foods that you ate for dinner last night, on a sheet of notebook paper, break each food down into any known components. For example, if the food was pepperoni pizza, the components could be as follows: For the crust, dough in the form of wheat flour, egg, and water; for the topping, tomatoes, milk in the form of cheese, and beef and pork in the pepperoni.

☐ 2. Now identify whether the ingredients came from a plant or an animal. Mark the plant ingredients with a “P” and the animal ingredients with an “A.”

☐ 3. If the food came from an animal, list several foods that the animal eats. For instance, the beef and pork can be broken down further into the foods that were consumed by the beef or the pig—corn or wheat. Continue this dissection of each food item until a plant is reached.

☐ 4. At this point, you should begin drawing your food webs. To start, at the bottom of the newsprint, draw any plants that you may have consumed, either directly or as a food of any animals you ate (for example, wheat, tomatoes, corn).

☐ 5. Next, above the plants on the newsprint, draw the animals that eat those particular plants (chickens, cattle, pigs).

☐ 6. Next, above the animals from Step 5, draw any animals that may eat them.

☐ 7. Last, at the top of the food web, draw a picture of yourself.

☐ 8. Using a black marker, label your webs with the following terms:
- Producer
- Primary consumer
- Secondary consumer
- Tertiary consumer
- Autotrophs
- Heterotrophs

☐ 9. From each producer, draw a colored line to the primary consumer that eats it.

☐ 10. From each primary consumer, draw a line to any secondary consumers that may eat the primary consumer. Use a different color from the one you used in Step 9.

☐ 11. If any secondary consumers eat a producer, connect them with yet another color.

Follow-up Discussion Questions

Review:

1. Summarize what you have learned so far while doing this activity.

2. Which of the animals on your list eat only plants?

These animals are called ______________________________

3. Which of the foods consumed by animals are also foods that you eat?

The term for an animal that eats both plants and animals is ______________________________

4. Are there any animals that eat only other animals? Give examples.

These animals are called ______________________________

Interpretive:

5. The webs you made appear to be unidirectional. What happens to the waste produced by the animals, and/or what happens when the animals die?

6. What would you call an organism that recycles things like waste products?

Reflective:

7. What did you like best about the activity?

8. What would you change and why?

Analyzing Food Webs

WORKSHEET

Task: Use the model food web provided to answer the following questions.

1. How many producer species? List.

2. How many primary consumers? List.

3. How many secondary consumers? List.

4. How many tertiary consumers? List.

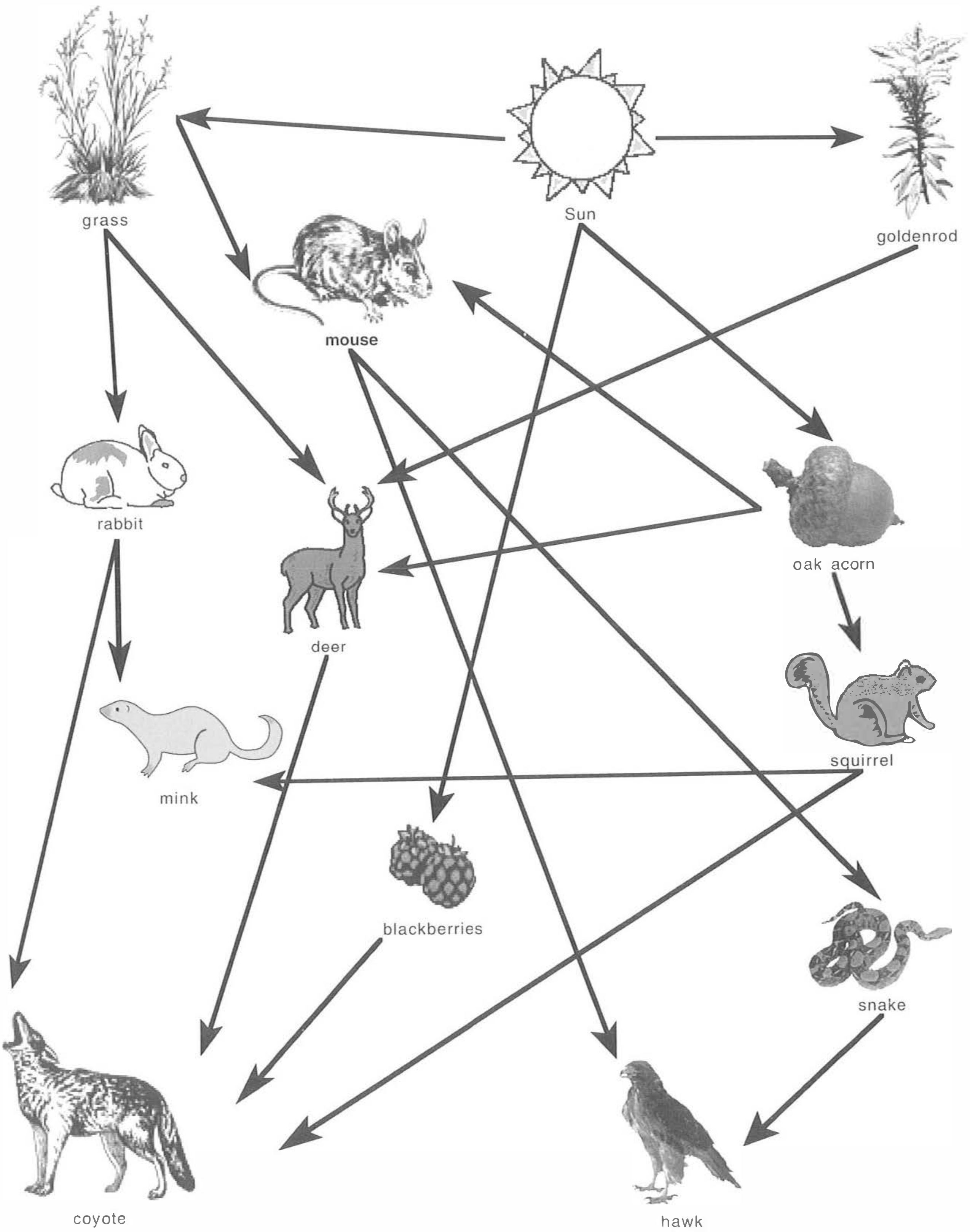
5. List the members of the longest food chain.

6. Do any organisms belong to two trophic levels? Which ones and why?

7. What essential food web role has been left out of the web?

8. Which species is at the highest possible trophic level in this web? Why?

MODEL OF A FOREST EDGE FOOD WEB



Pond Investigation I

Activator/Connector

What kinds of animals might you expect to find in a pond?

Describe insect life cycles. What are the differences and similarities between *complete* and *incomplete metamorphosis*?

Activity Purpose

In this activity, in order to begin exploring some of the organisms and relationships in an ecosystem, you will use collecting nets to retrieve organisms from a nearby pond. Back in the lab, you will use microscopes and field guides to identify those organisms.

General Background

Ponds are useful sites for field studies because of the *diversity*, or number of different kinds, of collectible and identifiable species. In general, most of the organisms collected in a pond are *macroinvertebrates*, visible with the naked eye and having no internal skeletons. These include adult insects and immature stages, or *larvae*. The instructor will demonstrate the proper use of the collecting nets and other equipment before collecting begins. You will be gathering specimens from both the water and the pond bottom, or *substrate*.

The pond is on private property. Please show respect for the pond and the surrounding area. Leave behind no trash, including cigarette butts, and do not pick flowers or dig up or destroy plants.

Vocabulary

diversity, substrate, macroinvertebrate, larvae, complete metamorphosis, incomplete metamorphosis

Learning Outcomes

After completing this activity, you will be able to:

Content

- Identify a variety of different macroinvertebrates inhabiting a local pond

Inquiry Skills

- Determine the relative abundance of the various macroinvertebrates inhabiting the pond
- Develop various hypotheses that explain why certain inhabitants are less abundant than others

Lab Skills

- Collect aquatic macroinvertebrates using nets and other collecting tools
- Use a dissecting microscope
- Use identification guides

Activity Sequence

1. Gather equipment and travel to pond

2. Learn how to use equipment and gather specimens from pond

3. Return to lab and use microscopes and field guides to identify organisms collected

Materials

Field

- Collecting nets
- Buckets for holding organisms and pond water
- Enamel or plastic pans for sorting and viewing aquatic invertebrates
- Meter sticks
- Hip waders—a pair per sampling team
- Rubber boots—for use by nonsampling students
- Tweezers for moving organisms within the containers
- Pipettes for moving organisms
- Clipboard, paper, and pen or pencil for recording observations

Materials

In Lab

- Dissecting microscopes
- Tweezers
- Pipettes
- Probes
- Plastic petri dishes for holding organisms
- Identification guides
- Plastic pipettes/eyedroppers
- Drawing materials

Procedure

Part A (in the field)

☐ 1. Collect all the field equipment and materials to bring to the pond.

☐ 2. Observe the pond and surrounding area. Discuss your observations with the class.

☐ 3. Observe the instructor's demonstration of the proper equipment handling techniques and proper use of the collecting tools.

☐ 4. Collect samples in the manner demonstrated.

☐ 5. Observe and record the relative abundance of each type of organism. A general observation is all that is necessary; an accurate count is not required.

☐ 6. Choose a representative sample of each type of organism to place in buckets (with water) to bring back to the lab.

Part B (in the lab)

☐ 1. Using microscopes and identification books, identify as many organisms as possible.

☐ 2. Record your organisms on a class list of organisms.

☐ 3. Sketch at least three of the organisms that you observed, using the sheets provided at the end of this handout.

Follow-up Discussion Questions

Review:

1. How many different species were identified?

2. What species were the most abundant?

3. What organisms had low numbers?

4. What did you learn about macroinvertebrates that you did not know before?

Interpretive:

5. Give two possible hypotheses as to why you think the pond would have so many of the most abundant organisms.

6. Give some hypotheses as to why you think numbers of other organisms were low.

Reflective:

7. What more would you like to know about macroinvertebrates?

8. What did you like and dislike about this lab?

9. What aspect of this lab was most difficult for you and why?

10. What did it teach you about how you learn best?

POND ORGANISM SKETCH

Name:

Date:

Organism:

Observations:

Sketch:

POND ORGANISM SKETCH

Name:

Date:

Organism:

Observations:

Sketch:

POND ORGANISM SKETCH

Name:

Date:

Organism:

Observations:

Sketch:

Pond Investigation II

Activator/Connector

Recall the steps in the scientific process. What parts of this process were used in Pond Investigation I?

Recall your observations of the pond in Pond Investigation I. In what parts of the pond were the aquatic invertebrates collected?

If the pond is an ecosystem, brainstorm some of the "mini" ecosystems or habitats within a pond.

Activity Purpose

In this lab-based activity, you will develop hypotheses regarding the effect of depth on various organisms living in a pond, then design an experiment, perform the experiment, and analyze the results in the lab.

General Background

Ponds are useful sites for field studies because of the *diversity*, or number of different kinds, of collectible and identifiable species. In general, most of the organisms collected in a pond are *macroinvertebrates*, visible with the naked eye and having no internal skeletons. These include adult insects and immature stages, or *larvae*. The instructor will demonstrate the proper use of the collecting nets and other equipment before collecting begins. You will be gathering specimens to test your hypothesis.

Remember that this pond is on private property and treat the area with respect.

Vocabulary

diversity, substrate, macroinvertebrate, larvae, complete metamorphosis, incomplete metamorphosis

Learning Outcomes

After completing this activity, you will be able to:

Content

- Identify a variety of different macroinvertebrates inhabiting a local pond
- Describe the effect of depth on aquatic biodiversity

Inquiry Skills

- Develop working hypotheses and predictions for a given investigative question
- Design experiments to test hypotheses
- Determine and compare the abundance of macroinvertebrates inhabiting different depth zones in a pond
- Decide whether data support hypotheses

Lab Skills

- Collect aquatic invertebrates using nets and other collecting tools
- Use a dissecting microscope
- Use identification guides

Activity Sequence

1. Discuss the investigative question

2. Develop hypotheses and predictions

3. Develop experimental procedures

4. Gather equipment and travel to pond

5. Carry out designed procedure

6. Identify and quantify collected organisms

7. Analyze data

8. Follow-up discussion questions

Materials

Field:

- Collecting materials such as nets, closable jars, etc.
- Buckets for holding organisms and pond water
- Enamel or plastic pans for sorting and viewing aquatic invertebrates
- Thermometers (optional)
- Meter sticks—several
- Hip waders—a pair per sampling team
- Rubber boots—for use by nonsampling students
- Tweezers for moving organisms within the containers

Materials

In Lab:

- Dissecting microscopes
- Tweezers
- Probes
- Plastic petri dishes for holding organisms
- Identification guides
- Plastic pipettes/eyedroppers
- Calculators
- Graph paper

Procedure

Part A (in the lab)

1. In your lab groups, discuss the following investigative question: *Does pond depth have an effect on aquatic invertebrate diversity?*

☐ a. Identify the dependent and independent variables in the question.

Dependent variable:

Independent variable:

☐ b. Develop and record a hypothesis which answers the investigative question.

Hypothesis:

☐ c. Make a specific prediction based on your background knowledge and your knowledge of the pond ecosystem which you observed during Pond Investigation I.

Prediction:

☐ 2. Discuss hypotheses and predictions with the entire class.

☐ 3. In your lab groups, devise an experimental procedure which will test your predictions. Include the specific equipment necessary to carry out your procedure.

Procedure:

Equipment necessary:

☐ 4. Discuss procedures with the entire class. Agree on a procedure which the entire class will use.

Procedure to be followed:

Equipment necessary:

Part B (sampling in the field)

☐ 1. Ready all relevant field equipment and materials to take to the pond under study.

☐ 2. Observe the sampling areas and depths carefully. Revise your hypothesis and prediction if it seems necessary.

Hypothesis:

Prediction:

☐ 3. Carry out the procedure designed by the class to test the investigative question. Use careful and consistent collection methods, and be sure to clearly label all containers holding aquatic invertebrates with the appropriate depth where the sample was found.

Part C (in the lab)

☐ 1. The class will be divided into groups to identify those organisms collected at different depths, one group for each depth. Using the techniques you learned in Pond Investigation I, identify and record the organisms collected for your assigned depth.

Organisms:

☐ 2. Record which organisms had large numbers of individuals and which organisms had few individuals.

☐ 3. Record the organisms you identified on a class list of organisms by depth.

Part D (data analysis)

Record the results from the collection and identification procedures:

☐ 1. List taxa found at all depths.

☐ 2. List taxa found only at a single depth, and the depth at which they were found.

☐ 3. For each depth, calculate the percentage of the total number of different taxa which were unique to that depth.

☐ 4. For each depth, calculate the percentage of the total number of different taxa which were the same in all depths.

☐ 5. Graph the class data to show numbers of organisms unique to a depth and numbers of organisms overlapping depths.

Follow-up Discussion Questions

Review:

1. Which organisms overlapped at each depth?

2. Which organisms were unique to each depth?

Interpretive:

3. What conclusions can you draw from your data? Did the data support your hypothesis and prediction?

4. Based on your data and observations, develop one or more new hypotheses as to why the different depths had the diversities observed.

5. Based on your data and observations, develop one or more new hypotheses as to why there were different numbers of individuals for the different taxa.

6. What are possible sources of error in your data?

Reflective:

7. What did you learn about pond ecology?

8. What did you learn about the nature of scientific inquiry?

9. What aspects of this investigation were most suited to your learning style?

10. What aspects of the lab were most challenging?

Mussel Beach: A Simulation of Evolutionary Change

Activator/Connector

Pretend that you are a mussel living on the shoreline. List some ways that you might be killed.

Activity Purpose

In this activity, you will be a carrying out a simulation that shows how evolutionary change might occur.

General Background

Evolution can be a difficult subject to study in real time. Evolutionary change generally occurs at extremely slow rates. This simulation is designed to speed up the process, so we can get a glimpse of the process in a shorter time frame. Set in a rocky coastline habitat, this evolution simulation has two variations: the *oystercatcher* and the *driftwood log*. In the oystercatcher simulation, a predator (the oystercatcher bird) will visually "hunt" and "kill" its prey (mussels) in the coastline habitat. In the driftwood log simulation, mussels will be "killed" by a driftwood log smashing into the coastline habitat. After performing the simulations, you will graph your data, and then all data will be grouped together in large class graphs. You will then compare the two simulations and discuss types of evolutionary change.

Learning Outcomes

After completing this activity, you will be able to:

Content

- Define the concepts of natural selection and genetic drift
- Differentiate between natural selection and genetic drift with respect to how they influence evolutionary change in small populations

Inquiry Skills

- Display data in both tabular and graphic form
- Compare and contrast related sets of data and draw conclusions
- Identify sources of experimental error

Communication Skills

- Write a scientific lab report that summarizes the experimental simulation

Activity Sequence

1. Instructor demonstrates the two simulations

2. Students run simulations in teams and record data

3. Graph data in teams

4. Share and graph all class data generated

5. Discuss results

6. Name types of evolutionary change and discuss simulations

Materials

Each student simulation team needs:

- A container with 40 mixed beads—10 beads in each of four colors
- A piece of multicolored fabric with a complex pattern, about 50cm x 30cm
- Four small containers, each with beads of one of the four colors (about 40 beads in each container)
- Graph paper or graph templates
- Colored markers in the same colors as the beads
- Two labeled petri dishes:
  —"Survivor" dish
  —"Graveyard" dish

Driftwood Log teams need, in addition,

- Masking tape, sticky side out, wrapped around three pencils

Investigative Question

What is going to happen to each of the four mussel/bead subpopulations after the oystercatcher and driftwood log simulations are run?

What do you think will happen to each of the four colors of beads when the oystercatcher simulation is performed ?

What is the basis for your prediction? (hypothesis)

What do you think will happen to each of the four colors of beads when the driftwood log simulation is performed?

What is the basis for your prediction? (hypothesis)

Procedure—Oystercatcher Teams

☐ 1. Working in pairs, collect the materials and spread out the fabric.

☐ 2. Identify your roles in the team: the *oystercatcher* hunts the mussels; the *habitat manager* manages the fabric and bead counts.

☐ 3. The habitat manager sprinkles the 40 beads onto the fabric and spreads them evenly.

☐ 4. The oystercatcher picks out 30 beads in a predatory manner (one at a time). Do this by looking at the fabric and taking the first bead that stands out. Look away between each "hunt."

☐ 5. Put the bead victims in the "graveyard" dish. The habitat manager counts them carefully as they are hunted, until 30 are removed from the fabric and placed in the dish.

☐ 6. Stop hunting when 10 survivors are left on the fabric.

☐ 7. Remove the remaining 10 bead survivors from the fabric and place them in the "survivor" dish. Count the number of each color and record it in the data sheet provided.

☐ 8. Multiply the number of each survivor color by 3 and put the results in the data sheet. The four totals should add up to 30.

☐ 9. Add the number of survivors of each color to the corresponding total from step 8 and record the results in the Totals column of the data sheet. Make sure the total number of all four colors is 40.

☐ 10. Then, take the numbers of beads of each color shown in the Totals column from the four single-color bead containers, and once again scatter 40 beads onto the fabric to start round two.

☐ 11. Repeat steps 4 through 10 two more times for a total of three rounds.

Procedure—Driftwood Log Teams

☐ 1. Working in pairs, collect the materials and spread out the fabric.

☐ 2. Identify your roles in the team: the *driftwood log* "crashes" a pencil onto the fabric. The *habitat manager* manages the fabric and bead counts.

☐ 3. The habitat manager sprinkles the 40 beads onto the fabric and spreads them evenly.

☐ 4. With eyes closed, the driftwood log gently rolls or drops the taped pencil randomly into the "habitat" and removes the beads that stick to it. **Be sure to watch out for escapees that get knocked off of the fabric!! Put them back on the fabric!**

☐ 5. Put the beads from the pencil in the "graveyard" dish, counting them carefully as they are hunted, until a total of 30 are removed. It may take a few rolls of the pencil to achieve the precise number of 30 beads. If a roll yields a cumulative number "killed" larger than 30, beads from that roll should be put back on the fabric and the pencil rerolled, if necessary repeating this procedure of replacing and rerolling until exactly 30 beads have been removed.

☐ 6. Check to make sure 10 survivors are left in the habitat.

☐ 7. Remove the remaining 10 bead survivors from the fabric and place them in the "survivor" dish. Count the number of each color and record it in the data sheet provided.

☐ 8. Multiply the number of each survivor color by 3 and put the results in the data sheet. The total of the four colors should add up to 30.

☐ 9. Add the number of survivors of each color to the corresponding total from step 8 and record the results in the Totals column of the data sheet. Make sure the total number of all four colors is 40.

☐ 10. Then, take the numbers of beads of each color shown in the Totals column from the four single-color bead containers, and once again scatter 40 beads onto the fabric to start round two.

☐ 11. Obtain a new taped pencil and repeat steps 4 through 10 two more times for a total of three rounds.

Data Analysis and Interpretation

Data Tables

Sample Data

First, count the number of ***survivors*** of each color and enter that number in the Survivors column below.

Second, multiply the number of survivors by 3.

Third, add the number of survivors to the total from the previous column.

The total is the number of beads that gets placed on the fabric for the next round. (Should be a total of 40)

Survivors			Totals
3 Green	Survivors x 3 = 9	9 + 3 (Survivors) =	12
3 Blue	Survivors x 3 = 9	9 + 3 (Survivors) =	12
3 White	Survivors x 3 = 9	9 + 3 (Survivors) =	12
1 Purple	Survivors x 3 = 3	3 + 1 (Survivors) =	4

Mussel Beach Data

Round One

Survivors			Totals
__ Green	Survivors x 3 = ____	____ + ____ =	
__ Blue	Survivors x 3 = ____	____ + ____ =	
__ White	Survivors x 3 = ____	____ + ____ =	
__ Purple	Survivors x 3 = ____	____ + ____ =	

☐ Place the number of beads of each color indicated in the Totals column back in the habitat for the next round.

Round Two

Survivors			Totals
__ Green	Survivors x 3 = ____	____ + ____ =	
__ Blue	Survivors x 3 = ____	____ + ____ =	
__ White	Survivors x 3 = ____	____ + ____ =	
__ Purple	Survivors x 3 = ____	____ + ____ =	

☐ Place the number of beads of each color indicated in the Totals column back in the habitat for the next round.

Round Three

Survivors			Totals
__ Green	Survivors x 3 = ____	____ + ____ =	
__ Blue	Survivors x 3 = ____	____ + ____ =	
__ White	Survivors x 3 = ____	____ + ____ =	
__ Purple	Survivors x 3 = ____	____ + ____ =	

Do not place any more beads back on the fabric; the simulation ends after three rounds.

Graphing

☐ 1. Display your team's results (after three rounds) in a graph with the vertical (Y) axis being the total number of beads/mussels after each round for each of the four colors (include also the starting populations, 10 of each color), and the horizontal (X) axis being the three rounds plus "round zero," the starting point. Use the blank graph template or poster paper provided. Use colored markers for the beads/mussels.

☐ 2. Post your team's data for all to see, or copy or photocopy the graphs so that each team has access to all data collected.

Follow-up Discussion Questions

Review:

1. Compare and contrast the oystercatcher graphs of the whole class:
   a. List some ways that the oystercatcher graphs are similar.

   b. List some ways that the oystercatcher graphs are different.

2. Compare and contrast the driftwood log graphs of the whole class:
   a. List some ways that the driftwood log graphs are similar.

   b. List some ways that the driftwood log graphs are different.

3. Compare and contrast the graphs of the driftwood logs vs. the oystercatchers:
   a. List some ways that the driftwood log graphs and oystercatcher graphs are similar.

   b. List some ways that they are different.

4. Compare the results to your original predictions and hypotheses for both the oystercatcher and the driftwood log simulations: Do the results support your original hypothesis and predictions? Explain.

a. Oystercatcher:

b. Driftwood Log:

5. **The Simulation:** What does each of the simulation components represent in nature?

- The beads____
- The pencil____
- The step of increasing the 10 survivors to 40____________________
- The fabric____
- The bead colors____________________________________
- The elimination of bead colors____________________________
- The different rounds __________________________________

6. What are at least two other variables that affected how the simulation played out? Do these same variables exist in nature?

Interpretive:

7. The oystercatcher simulation was designed to represent the process in nature called ______________________. The driftwood log simulation was designed to represent the process in nature called ______________________.

8. If the numbers of each mussel subpopulation were much larger—in the thousands or even millions—how would this affect the simulation?

9. What if the two mechanisms, driftwood logs and oystercatchers, were both operating in the same simulation? Predict the outcome.

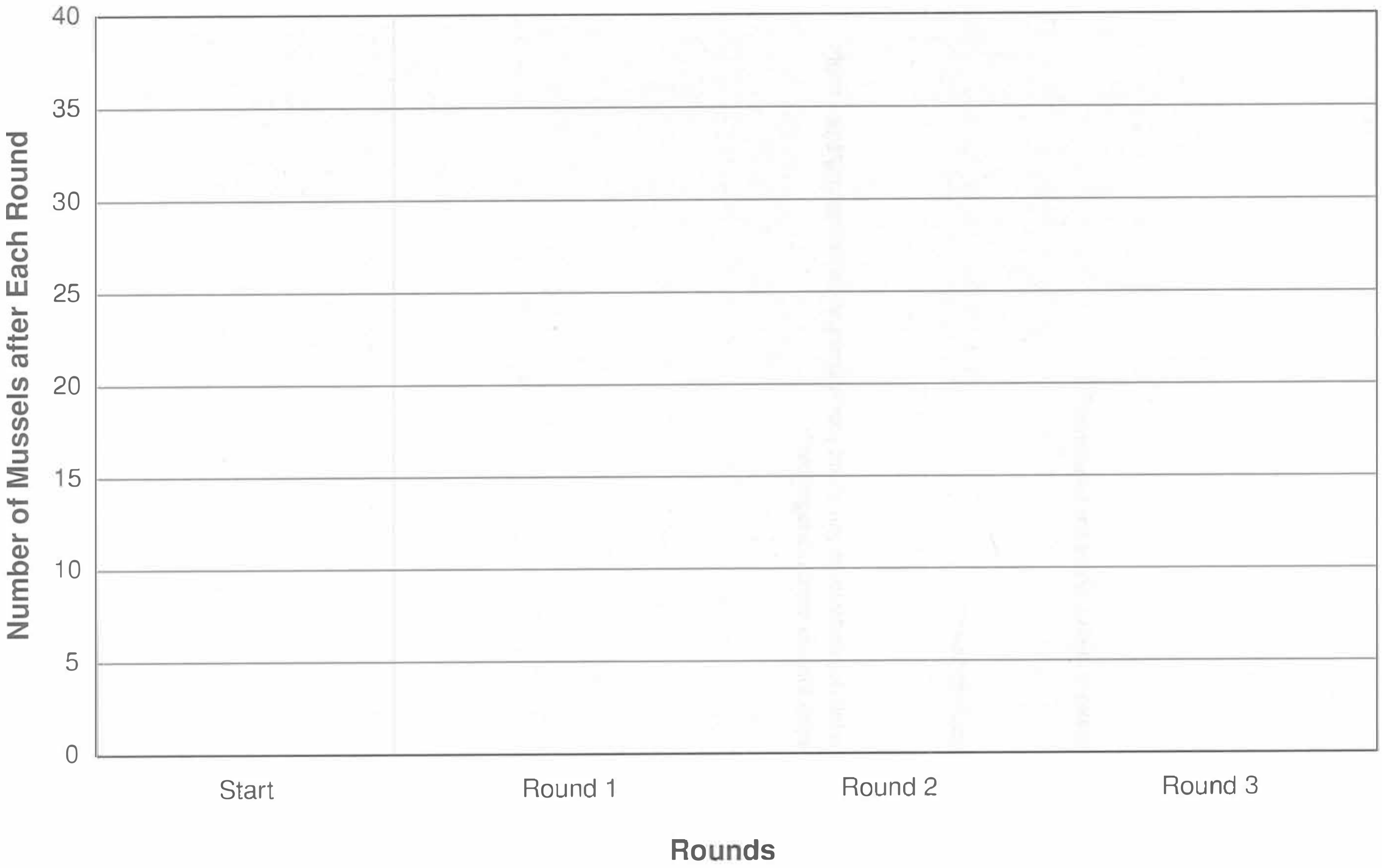
Reflective:

10. What did you like or dislike about the simulation?

11. How would you improve it?

12. What did this lab demonstrate to you about your learning style? What strategies might you employ to make this lab more manageable?

Oystercatcher Simulation



Driftwood Log Simulation

Phylogenetic Trees

Activator/Connector

People often look similar to members of their own family and different from those of other families. What characteristics are shared by your family that are different from other people you know?

Which is more closely related evolutionarily to humans, bread mold, a maple tree, or a horse? How do you know this?

Activity Purpose

In this lab-based activity, you will study evolutionary relationships among seven fish species and arrange them in a phylogenetic tree that illustrates these relationships.

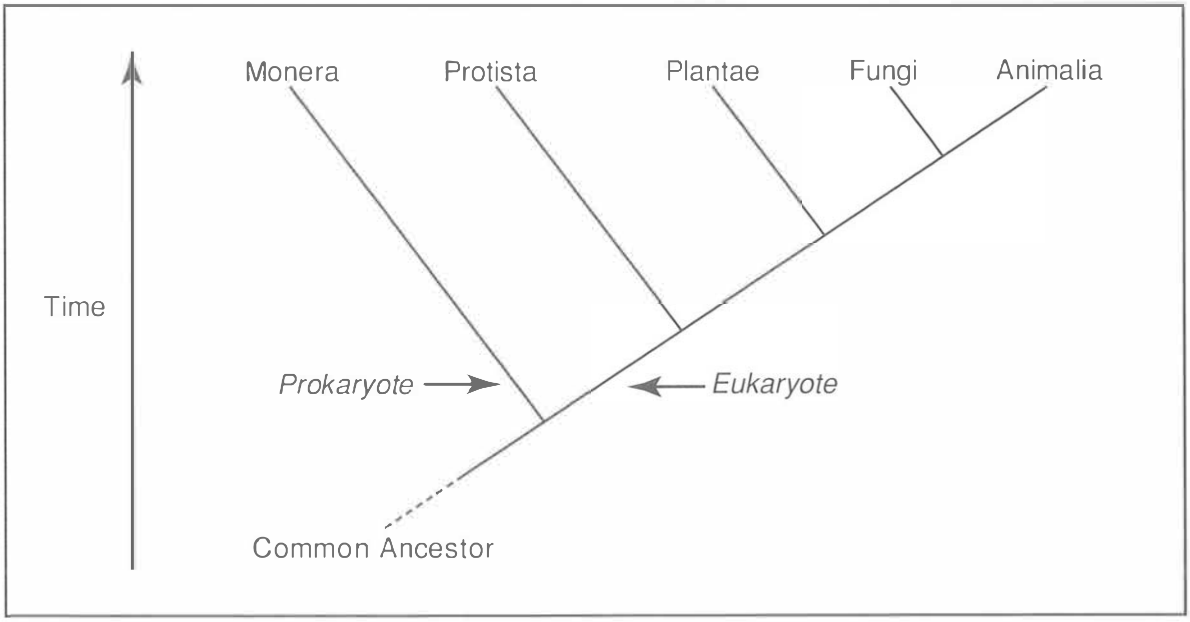
General Background

Evolutionary relationships between organisms can be determined based on how similar they are in morphology (e.g., coloration), behavior (e.g., mating pattern), biochemistry (e.g., protein amino acid sequence), and other characteristics. The greater the number of characteristics that are shared, the greater the likelihood that two organisms have a common ancestor.

Scientists illustrate the degree of relatedness between organisms graphically using a *phylogenetic tree*. In the example on the next page, the relationship between organisms in the five classic kingdoms is illustrated. Branch points on the tree indicate a points of divergence where organisms from each branch differ in at least one characteristic. For example, the first branch point is drawn to differentiate the one kingdom (Monera = bacteria) that is composed of prokaryotes from the other kingdoms that are composed of eukaryotes.

Vocabulary

phylogenetic tree, gel electrophoresis, protein



Learning Outcomes

After completing this activity, you will be able to:

Content

- Describe the structure and purpose of phylogenetic trees
- Construct phylogenetic trees to illustrate the evolutionary relationships among seven fish species based on several criteria, including habitat, anatomy, diet, and protein electrophoretic banding patterns

Inquiry Skills

- Formulate testable hypotheses
- Interpret elecrophoretic banding patterns
- Decide whether data support hypotheses

Lab Skills

- Load samples into a gel
- Prepare solutions for protein electrophoresis (optional)

Communication Skills

- Write a scientific lab report that accurately summarizes the experiment

Activity Sequence

Day One:

1. Small groups practice constructing a phylogenetic tree by arranging common foods into levels of evolutionary relatedness (Procedure Part A)

2. Small groups develop a hypothesized phylogenetic tree for seven fish species based on their habitats, anatomy, and diets (Procedure Part B)

3. Carry out gel electrophoresis procedure with proteins for seven fish species (Procedure Part C)

Day Two:

4. Analyze the protein gel results for the fish and develop a new phylogenetic tree (Procedure Part D)

5. Follow-up discussion questions

Materials

- 8 small tubes containing isolated fish protein (7) and protein standard (1)
- Gel in casting tray (*fragile; handle with care!*)
- Electrophoresis power supply, electrodes, and chamber
- 100 mL Tris-glycine-SDS (buffer)
- Boiling water bath
- Small-tube rack
- Micropipetter
- Protective goggles and gloves
- Student handout

Procedure

Part A: Phylogenetic Tree of Common Foods

Check off each step as you proceed through the lab.

☐ 1. Form groups of 2–3 students.

☐ 2. In the space provided, place the following foods into a phylogenetic tree based on the closeness of their evolutionary relationship: *lettuce, mushroom, cow (milk)*, and *sardines*. Indicate a characteristic that differentiates one branch from another at each branch point.

Draw your tree here:

Part B: Fish Phylogenetic Tree Based on Habitat, Morphology, and Diet

☐ Using the following table, hypothesize a phylogenetic tree for these fish species: cod, swordfish, tuna, catfish, flounder, perch, and halibut:

Fish species	**Characteristic**		
	Habitat	Dorsal fin number	Diet
Catfish *Ictalurus spp.*	Freshwater river bottoms	2	Invertebrates, fish
Cod *Gadus spp.*	Marine, medium depth	3	Herring, eel, shoal fish
Flounder *Paralichthys spp.*	Marine, coastal bottoms	1	Mollusks, shrimp, fish
Halibut *Hippoglossus spp.*	Marine, deep ocean bottoms	1	Fish, large crustaceans
Perch *Perca spp.*	Freshwater lakes and ponds, medium depth	2	Larvae, fish eggs, small fish
Swordfish Xiphias gladus	Marine, medium depth	2	Different size fish, squid
Tuna *Thunnus spp.*	Marine, medium depth	2	Small fish, squid, shrimp, crab

Draw your tree here:

Part C: Gel Electrophoresis with Fish Proteins

Gel electrophoresis

1. Prepare fish protein samples.
   - ☐ Put the screw-top tubes containing the fish protein samples AND the protein standard into a rack.
   - ☐ Place the rack into a boiling water bath for 3–5 minutes. DO NOT IMMERSE LIDS!
2. Load the samples into the gel.
   - ☐ Using a micropipetter, load 10 µl of each sample into separate wells. Each student will load one sample into one well. Be sure to keep track of which sample is placed in each well!
3. Run the gel.
   - ☐ Fasten the top of the electrophoresis chamber in place; be sure to keep the black and red sides together!
   - ☐ Attach the electrodes to the power supply, and run the gel at 100–135 volts.
   - ☐ Double-check that the electrophoresis is working.
     Are the tiny bubbles moving from the black end toward the red end?
     Can you see the blue dye of the samples moving into the gel itself?
4. The gel will need to run for 1–2 hours.

Part D: Analyzing the Gel Banding Patterns

☐ 1. Accurately sketch the banding pattern of your gel in the space that follows.

2. To determine the degree of relatedness between species as indicated by the bands, interpret the gel using some of the following techniques:

- ☐ Number the lanes 1, 2, 3, etc., and label the bands a, b, c, etc., in order to better organize your group discussion of the gel.
- ☐ b. Initially, identify lanes with the most unique banding patterns. These would include, for example, the one with the fewest bands, the one with the most bands, or one with a pattern of bands that makes it stand out from the other lanes.
- ☐ c. Look at the number of bands that different lanes have in common. This may be easier if you redraw the gel on a piece of scrap paper and cut out the lanes so they can be moved next to each other for comparison.

☐ 3. Use your gel interpretation to draw a new phylogenetic tree for the fish species in the space that follows.

Follow-up Discussion Questions

Review:

1. What are the main concepts you have learned from this lab activity?

2. Why are protein standards included in this experiment?

3. Why was electricity used during the electrophoresis procedure?

4. Why do scientists use phylogenetic trees?

Interpretive:

5. Does the gel banding pattern support only one type of phylogenetic tree, or are multiple trees possible based on the same data? Why?

6. Does the phylogenetic tree based on biochemical data correlate with the hypothesized tree based on habitat, morphology, and diet? Why or why not?

7. If fish DNA instead of protein were used for gel electrophoresis, do you think the banding pattern and the phylogenetic tree based on it would be similar to or different from those in this experiment? Why?

Reflective:

8. Are there sources of error in this experiment? How might they have affected the results?

9. Did the lab help your understanding of how phylogenetic trees are developed?

10. What did you like or dislike about this lab?

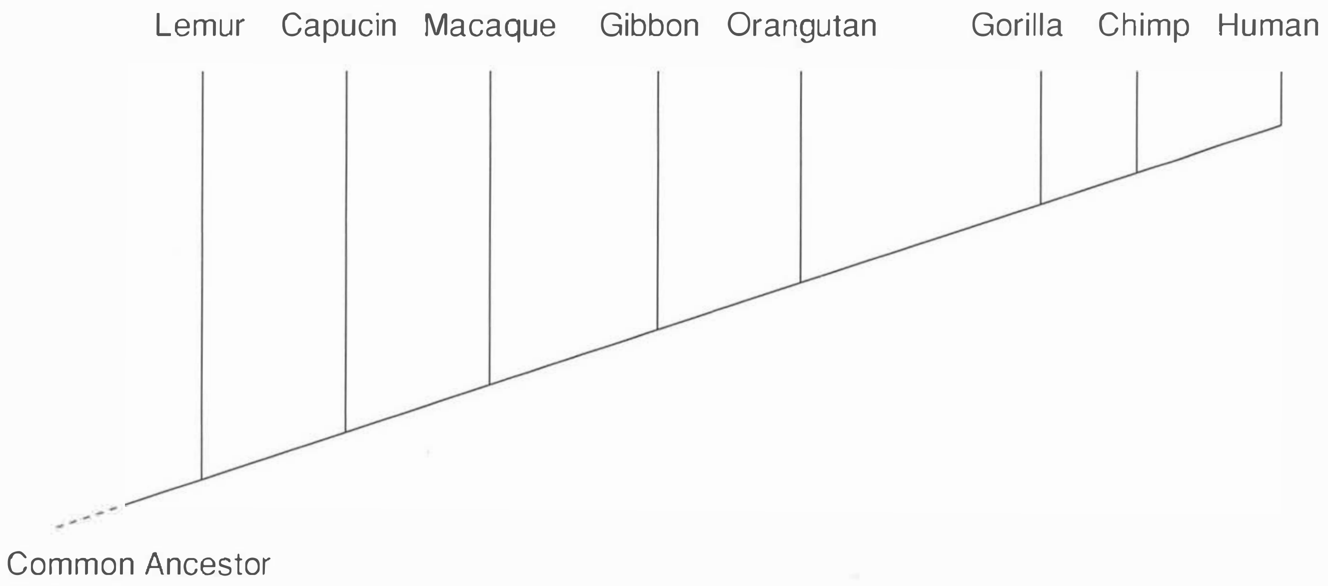
11. How can this lab be improved to make it a better learning experience?

Hypothetical Banding Pattern for a Protein Gel of Select Primates

Assignment: Create a phylogenetic tree for the hypothetical protein gel below.

A		▬				▬		▬	▬	A
B		▬	▬	▬	▬	▬	▬	▬	▬	B
C	▬	▬	▬		▬	▬	▬	▬	▬	C
D	▬		▬		▬		▬		▬	D
E										E
F									▬	F
G			▬		▬					G
H							▬			H
I		▬				▬		▬	▬	I
J		▬								J
K			▬	▬	▬					K
L										L
M				▬						M
N										N
O			▬	▬	▬	▬	▬			O
P		▬					▬	▬		P
Q	▬	▬	▬		▬	▬	▬	▬		Q
R	▬	▬				▬		▬		R
S										S
T	▬		▬		▬				▬	T
	Gibbon	Human	White-Faced Capucin	Brown Mouse Lemur	Pig-Tailed Macaque	Gorilla	Orangutan	Chimpanzee	Protein standard	
	1	2	3	4	5	6	7	8	9	

Answer:


Lemur
Capucin
Macaque
Gibbon
Orangutan
Gorilla
Chimp
Human
Common Ancestor

Cell Cycle Role-Play

Play Sequence

Act 1: Prelude

- **Scene 1** — A Day in the Life

- **Scene 2** — Copycats I

- **Scene 3** — Copycats II

Act 2: Sorting Out the Pieces

- **Scene 1** — Getting Some Breathing Room

- **Scene 2** — Line Dancing

- **Scene 3** — Homeward Bound

- **Scene 4** — There's No Place Like Home

Act 3: Finale

- **Scene 1** — Coming Apart at the Seams

Follow-up Discussion Questions

Review:

1. What biological stages and what cellular events take place in each of the acts and scenes? Fill in terms from the list below next to each act or scene in the play sequence on the previous page. Some terms may be used more than once or appear together with other terms in one stage.

Stages:

Mitosis
Anaphase
G_1
G_2
Telophase
S-Phase
Cytokinesis
Metaphase
Prophase
Interphase

Cellular events:

Cell membrane divides
DNA replicates
Spindle fibers form
Spindle fibers disappear
Sister chromatids align in one plane at center of cell
Chromosomes shorten and thicken
Chromosomes lengthen and become thin
Centrioles move to opposite poles
Cellular metabolism occurs
Daughter cells form
Centrioles replicate
Sister chromatids separate and move to opposite poles
Nuclear membrane forms
Nuclear membrane disappears

2. How do the daughter cells compare to each other and to the original cell in terms of the number and identity (colors) of their chromosomes?

3. What mechanism or mechanisms ensure that chromosomes similar in quantity and identity are partitioned into each daughter cell?

4. How do chromosomes differ from chromatids?

Interpretive:

5. How would the role-play need to be modified to represent the cell cycle in plant cells?

6. If a mistake occurred during mitosis and the spindle fibers failed to attach to the chromosomes, what do you think would be the consequence in terms of the number of cells formed and the number of chromosomes in each cell after cytokinesis took place?

Reflective:

7. Which part of the model is still unclear to you?

8. Did you find the role-play to be an effective learning instrument? How could it be improved as an activity?

9. Does the kinesthetic approach complement your learning style?

10. Do you have other ideas on how to better learn this material?

Environmental Factors and Enzyme Activity

Activator/Connector

What allows bread to rise?

Where do the bubbles in beer or champagne come from?

Activity Purpose

In this lab-based activity, you will design an experiment to test the effect of a particular environmental factor on the activity of catalase, an enzyme found in yeast.

General Background

Enzymes are organic catalysts that increase rates of biochemical reactions necessary to support life. Essentially, enzymes allow one or several *reactants* to be converted chemically into one or several *products*. In today's lab, you will investigate the behavior and function of an enzyme in yeast. This enzyme, *catalase*, catalyzes the following reaction:

$$\underset{\textit{reactant}}{H_2O_2\text{ (peroxide)}} \xrightarrow{\text{catalase}} \underset{\textit{products}}{H_2O + \tfrac{1}{2}O_2\text{ (g)}}$$

Vocabulary

enzyme, reactant, product, reaction rate, solution

Learning Outcomes

After completing this activity, you will be able to:

Content

- Describe the functions of enzymes as catalysts
- Identify variables that affect enzyme activity

Inquiry Skills

- Formulate testable hypotheses
- Design experiments to test hypotheses
- Display data in both tabular and graphic form
- Calculate averages
- Decide whether data support hypotheses

Communication Skills

- Write a scientific lab report which accurately summarizes an experiment

Activity Sequence

1. Observe teacher demonstration of an enzyme reaction

2. Small groups choose an environmental variable and develop a hypothesis

3. Small groups design an experiment to test their hypothesis

4. Small groups collect and interpret data

5. Follow-up discussion questions

Materials

- 3% peroxide solution
- Dry, granulated yeast
- Felt cut into 2cm x 2cm squares
- Ice
- Dilute HCL (0.1 M)
- Dilute NaOH (0.1 M)
- pH paper or meter
- Stopwatch

Procedure

Part A: Teacher Demonstration

☐ 1. Dissolve 10–15 grains of yeast in 300 ml H_2O.

☐ 2. Dilute 10 ml 3% peroxide solution in 90 ml H_2O (100 ml total).

☐ 3. Using forceps, dip felt square into yeast solution until saturated.

☐ 4. Drop yeast-saturated felt square into diluted peroxide solution.

☐ 5. Record the total amount of time the felt takes to sink and rise back to the surface.

☐ 6. As a control, dip felt square into a 100% water solution and then drop it into the peroxide solution.

☐ 7. Record the result of the control and compare it to the behavior of the yeast-saturated felt square.

Part B: Discussion of Demonstration

☐ 1. Write the chemical equation for the reaction:

☐ 2. Why did the felt sink initially and then rise to the surface?

☐ 3. Brainstorm some variables that might affect this reaction:

Part C: Student Hypothesis Testing

☐ 1. Form groups of 2–3 students.

2. Each group:

☐ • Chooses a variable.

Variable:

☐ • Develops a hypothesis of how that variable might affect reaction time.

Hypothesis:

☐ • Develops and carries out a procedure to test the hypothesis (*reminder*: a minimum of three replications is required).

Procedure:

☐ • Predicts the outcome of the procedure.

Prediction:

Part D: Data Analysis and Interpretation

☐ 1. Record your data in the following table after filling in the appropriate levels of the variable your group has chosen:

Level of variable	**Time needed for felt to sink and rise to surface (seconds)**			
	Trial 1	Trial 2	Trial 3	Average

☐ 2. Calculate averages and graph them (level of variable vs. time to sink and rise).

☐ 3. Compare averages.

☐ 4. Did the data support the hypothesis?

☐ 5. Develop an explanation of why the hypothesis was or was not supported by the data.

Follow-up Discussion Questions

Review:

1. What are the main concepts you have learned from this lab activity?

2. What is the general role of enzymes for all organisms?

3. Based on the class data, what variables affect enzyme reaction rates and in what ways?

Interpretive:

4. If other levels of the variable were used, what results might be predicted for the experiment?

Reflective:

5. Are there sources of error in this experiment? How might they have affected the results?

6. What aspects of the activity most contributed to your understanding or were most challenging?

7. How might you apply this understanding to the next lab experiment you run?

8. How could this lab be improved?

Egg Osmosis—Demonstration

Activator/Connector

Have you ever noticed that sugar can "draw out" the juice from fruit pieces, creating a syrup? Have you ever used salt to draw out water (and some bitter-tasting solutes) from eggplant slices?

Activity Purpose

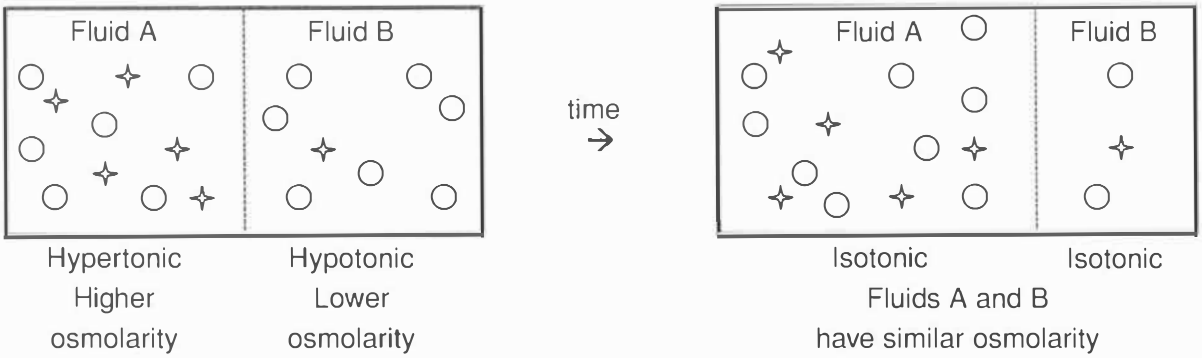
In this lab-based activty, you will place deshelled eggs in solutions that vary in osmolarity and then measure changes in egg weight over time. By observing whether there was a net gain or loss of water from the egg, you will be able to determine the isotonic point, or the percent solution that is *isotonic* to the internal egg fluid.

General Background

Diffusion is the passive movement of small dissolved particles, like ions and other molecules, from a region of higher concentration to a region of lower concentration. This process relies on thermal kinetic energy and not ATP. Cells use diffusion to exchange gases, nutrients, and waste products with their environment.

Cells also exchange water molecules with their environment, using a special form of diffusion called *osmosis*. Like diffusion, osmosis is a passive, thermally dependent process. Water moves from a region of lower solute concentration to one of higher solute concentration. *Osmolarity* is a measure of the concentration of dissolved particles in a solution.

The terms *hypertonic*, *hypotonic*, and *isotonic* are relative terms used to compare the osmolarities of different solutions. In the diagram that follows, two fluids that differ in osmolarity are separated by a membrane that is permeable to water but not to solutes. Fluid A, with the higher solute concentration (or osmolarity), is hypertonic *relative to* Fluid B, which has a lower osmolarity. Fluid B is hypotonic *relative to* Fluid A. If enough time is allowed for osmosis to occur, eventually the osmolarities of the two fluids will be the same, or isotonic. In the example, water moves via osmosis from B into A until the fluids are isotonic. As a result, the volume of B will get smaller while that of A will become greater.



Key: ○ = water molecule; ✧ = solute molecule

Vocabulary

osmosis, osmolarity, hypertonic, hypotonic, isotonic

Learning Outcomes

After completing this activity, students will be able to:

Content

- Define the process of osmosis
- Differentiate among the terms *hypertonic*, *hypotonic*, and *isotonic*

Inquiry Skills

- Display data in both tabular and graphic form
- Calculate averages

Lab Skills

- Use weighing balance

Communication Skills

- Write a scientific lab report that accurately summarizes the experiment

Activity Sequence

1. Obtain initial weights of deshelled eggs

2. Submerge eggs in 0%, 5%, 30%, and 50% solutions and weigh at 15-, 30-, and 45-minute intervals

3. Display data in both tabular and graphic form

4. Analyze data

5. Follow-up discussion questions

Materials

- Deshelled raw eggs
- Various percent solutions
- Beakers
- Spoon
- Weighing balance
- Timer
- Paper towels
- Graph paper

Procedure

☐ 1. There are four solutions for submerging eggs. The 0% solution is *hypotonic* relative to egg fluid, the 5% solution is probably the closest to being *isotonic*, and the 30% and 50% solutions are *hypertonic* relative to egg fluid. Knowing this information, predict whether an egg placed in each solution will lose weight (and water), gain weight, or stay the same.

Record your predictions:

Percent Solution	0%	5%	30%	50%
Weight: Gain, Lose, or Stay the Same?				

☐ 2. Record the initial weight of each egg in the table at the end of this section.

☐ 3. Before submerging eggs in their respective solutions, discuss with your lab partner(s) how to stagger measurements. Hint: It is impossible to weigh all the eggs at the same time.

☐ 4. Place one egg into the 0% solution, start the timer, and soak the egg for 15 minutes. Repeat for the 5%, 30%, and 50% solutions.

☐ 5. After soaking each egg for 15 minutes, remove it with a spoon and carefully dry it with a paper towel.

☐ 6. Weigh each egg and record the weights in the table; calculate differences in weight by subtracting the starting weights.

☐ 7. Return each egg to its solution and repeat step 6 after 30 minutes.

☐ 8. Return each egg to its solution and repeat step 6 after 45 minutes.

	Solutions							
Egg Weight in grams	0% weight	0% weight minus starting weight	5% weight	5% weight minus starting weight	30% weight	30% weight minus starting weight	50% weight	50% weight minus starting weight
Starting 0 min		N/A		N/A		N/A		N/A
15 min								
30 min								
45 min								

Data Display and Analysis

☐ 1. Calculate the amount of water gained or lost in each solution by subtracting the starting weight from its 15-, 30-, and 45-minute weights. A positive value indicates there has been a net gain of water over time, while a negative value indicates a net loss over time. Record values in the preceding table.

☐ 2. Construct a graph which illustrates the change in weight over time for the various solutions. Put the results for all four solutions on the same graph for easier comparison.

☐ 3. Estimate the percent solution that is isotonic to the fluid inside the egg and write your answer in the following space. Explain your answer.

Follow-up Discussion Questions

Review:

1. Summarize your observations and data.

2. Share and compare your results with those of other groups. Was there much variability in the results of different groups?

3. Did your results match your predictions? Explain.

4. Review the concepts of *hypotonic*, *hypertonic*, and *isotonic* and determine which term applied to the solutions used. Was the 0% solution hypertonic, isotonic, or hypotonic relative to the fluids inside the eggs?

Interpretive:

5. Relate the results of the lab exercise to osmosis within a cell or organism. Think of some scenarios where cells or organisms are exposed to changes in the osmolarity of their environment. For example, salmon migrate from seawater to freshwater to spawn. Predict what will happen to their cell volumes.

6. Suppose this experiment had been performed using older, not fresh, eggs. Eggs lose water by evaporation through pores in the shell. Thus, older eggs will be more dehydrated than fresher eggs. How might this affect the results of the experiment? Will the isotonic point change? In which direction?

Reflective:

7. List some sources of error for this lab.

8. Which aspect of the activity contributed most to your understanding of osmosis: group discussion? the hands-on manipulation?

9. Which aspects of the lab did you find most challenging? Explain.

10. Develop and share mnemonic devices for memorizing the terms associated with the process of osmosis.

Egg Osmosis—Structured Inquiry

Activator/Connector

Have you ever noticed that sugar can "draw out" the juice from fruit pieces, creating a syrup? Have you ever used salt to draw out water (and some bitter-tasting solutes) from eggplant slices?

Activity Purpose

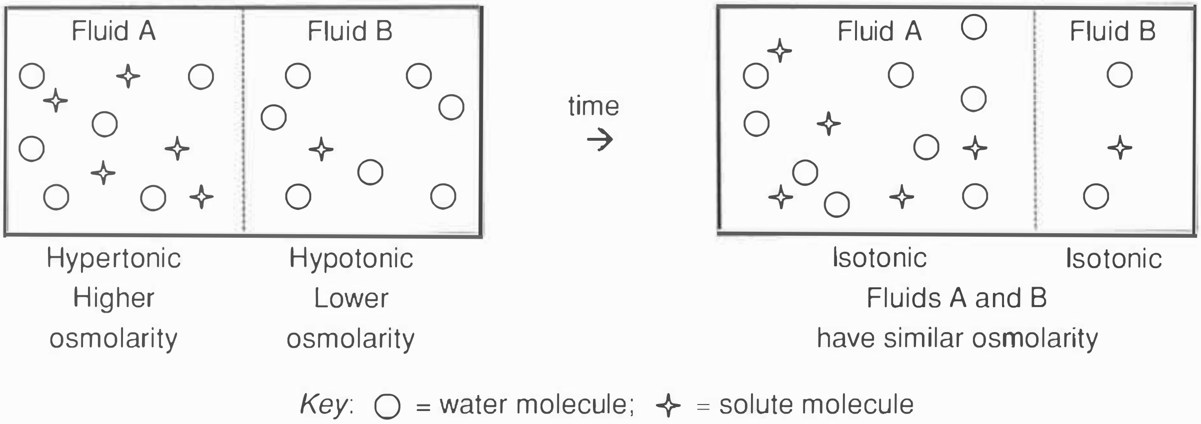
In this lab-based activity, you will place deshelled eggs in solutions that vary in osmolarity and then measure changes in egg weight over time. By observing whether there was a net gain or loss of water from the egg, you will be able to determine the isotonic point, or the percent solution that is *isotonic* to the internal egg fluid.

General Background

Diffusion is the passive movement of small dissolved particles, like ions and other molecules, from a region of higher concentration to a region of lower concentration. This process relies on thermal kinetic energy, not ATP. Cells use diffusion to exchange gases, nutrients, and waste products with their environment.

Cells also exchange water molecules with their environment using a special form of diffusion called *osmosis*. Like diffusion, osmosis is a passive, thermally dependent process. Water moves from a region of lower solute concentration to one of higher solute concentration. *Osmolarity* is a measure of the concentration of dissolved particles in a solution.

The terms *hypertonic*, *hypotonic*, and *isotonic* are relative terms used to compare the osmolarities of different solutions. In the diagram that follows, two fluids that differ in osmolarity are separated by a membrane that is permeable to water but not to solutes. Fluid A, with the higher solute concentration (or osmolarity), is hypertonic *relative to* Fluid B, which has a lower osmolarity. Fluid B is hypotonic *relative to* Fluid A. If enough time is allowed for osmosis to occur, eventually the osmolarities of the two fluids will be the same, or isotonic. In the example, water moves via osmosis from B into A until the fluids are isotonic. As a result, the volume of B will get smaller while that of A will become greater.



Vocabulary

osmosis, osmolarity, hypertonic, hypotonic, isotonic

Learning Outcomes

After completing this activity, students will be able to:

Content

- Define the process of osmosis
- Differentiate among the terms *hypertonic*, *hypotonic*, and *isotonic*

Inquiry Skills

- Display data in both tabular and graphic form
- Calculate averages

Lab Skills

- Use a weighing balance
- Make percent solutions

Communication Skills

- Write a scientific lab report which accurately summarizes the experiment

Activity Sequence

1. Make percent solutions

2. Obtain initial weights of deshelled eggs

3. Submerge eggs in solutions and weigh at 15-, 30-, and 45-minute intervals

4. Display data in both tabular and graphic form

5. Analyze data

6. Follow-up discussion questions

Materials

- Deshelled raw eggs
- Reagents to make percent solutions
- Beakers
- Spoon
- Weighing balance
- Timer
- Paper towels
- Graph paper

Procedure

Part A: Preparing Solutions

1. You will need to prepare four different percent (by volume) solutions to determine the isotonic point of your eggs. You will use dilutions of clear corn syrup with water to make solutions that can range anywhere between 0% (pure water) and 100% (pure corn syrup). Your group should start by deciding on the four different percent solutions to use for your experiment. Write your solution decisions in the spaces provided.

☐ Solution A _____%
☐ Solution B _____%
☐ Solution C _____%
☐ Solution D _____%

2. Now you'll need to calculate how much clear corn syrup and how much water to combine to make each solution. A 10% solution is one part corn syrup combined with nine parts

water. If you are going to make 500 ml of a 10% solution, then you'll combine 0.1 X 500 ml, or 50 ml, of clear corn syrup with 0.9 X 500 ml, or 450 ml, of water (see below). Use the following chart to calculate the amount of clear corn syrup and water you need to combine to make all four of your solutions.

EXAMPLE:

If you want 500 ml of a 10% clear corn syrup solution, you will need to combine:
10% or 0.1 X 500 ml = 50 ml clear corn syrup and 90% or 0.9 X 500 ml = 450 ml water

Your solutions:

To make 500 ml of a ______% solution, combine

______ X 500 ml = ________ ml syrup with ______ X 500 ml water

To make 500 ml of a ______% solution, combine

______ X 500 ml = ________ ml syrup with ______ X 500 ml water

To make 500 ml of a ______% solution, combine

______ X 500 ml = ________ ml syrup with ______ X 500 ml water

To make 500 ml of a ______% solution, combine

______ X 500 ml = ________ ml syrup with ______ X 500 ml water

Part B: Determining Changes in Egg Volume

☐ 1. Record the initial weight of each egg and the percent solutions you are using in the table at the end of this section.

☐ 2. Before submerging eggs in their respective solutions, discuss with your lab partner(s) how to stagger measurements. Hint: It is impossible to weigh all the eggs at the same time.

3. Place one egg into the first solution, start the timer, and soak the egg for 15 minutes. Repeat for the other three solutions.

☐ 4. After soaking each egg for 15 minutes, remove it with a spoon and carefully dry it with a paper towel.

☐ 5. Weigh each egg and record the weights in the table; calculate differences in weight by subtracting the starting weights.

☐ 6. Return each egg to its solution and repeat step 5 after 30 minutes.

☐ 7. Return each egg to its solution and repeat step 5 after 45 minutes.

	Solutions							
Egg Weight in Grams	A _____%	_____% minus starting weight	B _____%	_____% minus starting weight	C _____%	_____% minus starting weight	D _____%	_____% minus starting weight
Starting 0 min		N/A		N/A		N/A		N/A
15 min								
30 min								
45 min								

Data Display and Analysis

☐ 1. Calculate the amount of water gained or lost in each of your solutions by subtracting the starting weight from its 15-, 30-, and 45-minute weights. A positive value indicates there has been a net gain of water over time, while a negative value indicates a net loss over time. Record values in the preceding table.

☐ 2. Construct a graph which illustrates the change in weight over time for the various solutions. Put the results for all four solutions on the same graph for easier comparison.

☐ 3. Estimate the percent solution that is isotonic to the fluid inside the egg. Record your answer and explanation in the following space.

Follow-up Discussion Questions

Review:

1. Summarize your observations and data.

2. Share and compare your results with those of other groups. Was there much variability in the results of different groups?

3. Did your results match your predictions? Explain.

4. Review the concepts of *hypotonic*, *hypertonic*, and *isotonic* and determine which term applied to the solutions used. Was the 0% solution hypertonic, isotonic, or hypotonic relative to the fluid inside the eggs?

Interpretive:

5. Relate the results of the lab exercise to osmosis within a cell or organism. Think of some scenarios where cells or organisms are exposed to changes in the osmolarity of their environment. For example, salmon migrate from seawater to freshwater to spawn. Predict what will happen to their cell volumes.

6. Suppose this experiment had been performed using older, not fresh, eggs. Eggs lose water by evaporation through pores in the shell. Thus, older eggs will be more dehydrated than fresher eggs. How might this affect the results of the experiment? Will the isotonic point change? In which direction?

Reflective:

7. List some sources of error for this lab.

8. Which aspect of the activity contributed most to your understanding of osmosis: group discussion? the hands-on manipulation?

9. Which aspects of the lab did you find most challenging? Explain.

10. Develop and share mnemonic devices for memorizing the terms associated with the process of osmosis.

Egg Osmosis—Guided Inquiry

Activator/Connector

Have you ever noticed that sugar can "draw out" the juice from fruit pieces, creating a syrup? Have you ever used salt to draw out water (and some bitter-tasting solutes) from eggplant slices?

Activity Purpose

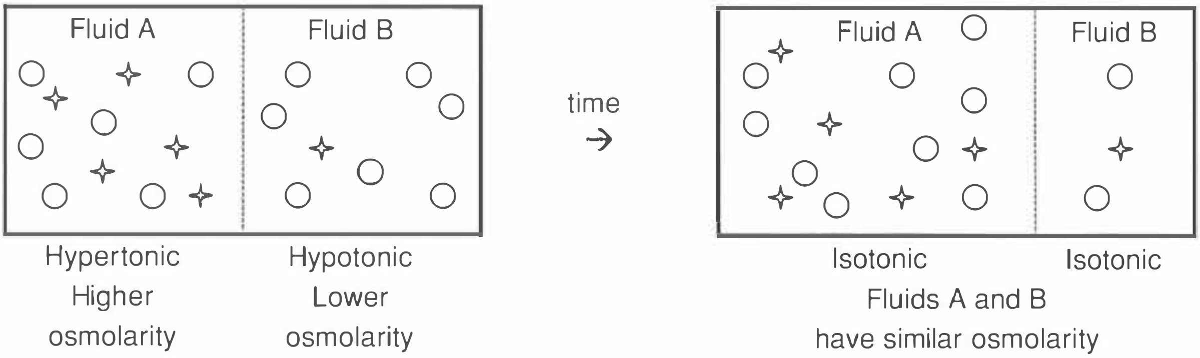
In this lab-based activity, you will place deshelled eggs in solutions that vary in osmolarity and then measure changes in egg weight over time. By observing whether there was a net gain or loss of water from the egg, you will be able to determine the isotonic point, or the percent solution that is *isotonic* to the internal egg fluid. In addition, you will be designing an experiment to examine how a variable of your choosing affects the process of osmosis.

General Background

Diffusion is the passive movement of small dissolved particles, like ions and other molecules, from a region of higher concentration to a region of lower concentration. This process relies on thermal kinetic energy and not ATP. Cells use diffusion to exchange gases, nutrients, and waste products with their environment.

Cells also exchange water molecules with their environment using a special form of diffusion called *osmosis*. Like diffusion, osmosis is a passive, thermally dependent process. Water moves from a region of lower solute concentration to one of higher solute concentration. *Osmolarity* is a measure of the concentration of dissolved particles in a solution.

The terms *hypertonic*, *hypotonic*, and *isotonic* are relative terms used to compare the osmolarities of different solutions. In the diagram that follows, two fluids that differ in osmolarity are separated by a membrane that is permeable to water but not to solutes. Fluid A, with the higher solute concentration or osmolarity, is hypertonic *relative to* Fluid B, which has a lower osmolarity. Fluid B is hypotonic *relative to* Fluid A. If enough time is allowed for osmosis to occur, eventually the osmolarities of the two fluids will be the same, or isotonic. In the example, water moves via osmosis from B into A until the fluids are isotonic. As a result, the volume of B will get smaller while that of A will become greater.



Key: ○ = water molecule; ✧ = solute molecule

Vocabulary

osmosis, osmolarity, hypertonic, hypotonic, isotonic

Learning Outcomes

After completing this activity, students will be able to:

Content

- Define the process of osmosis
- Differentiate among the terms *hypertonic*, *hypotonic*, and *isotonic*
- Identify variables that affect osmosis

Inquiry Skills

- Formulate testable hypotheses
- Design experiments to test hypotheses
- Display data in both tabular and graphic form
- Calculate averages
- Decide whether data support hypotheses

Lab Skills

- Make percent (by volume) solutions
- Use weighing balance

Communication Skills

- Write a scientific lab report which accurately summarizes the experiment

Activity Sequence

1. Develop a hypothesis, design an experiment to test it, and predict the outcome

2. Make percent solutions according to calculations

3. Obtain initial weights of deshelled eggs

4. Submerge eggs in solutions and weigh at 15-, 30-, and 45-minute intervals

5. Display data in both tabular and graphic form

6. Analyze data

7. Follow-up discussion questions

Materials

- Deshelled raw eggs
- Reagents to make percent solutions
- Beakers
- Spoon
- Weighing balance
- Timer
- Paper towels
- Graph paper
- Additional materials for student-designed component of activity

Procedure

Part A: Investigating Osmosis

1. You will be submerging eggs in clear corn syrup solutions that differ in osmolarity to observe changes in egg volume. In addition, you will design an experiment to investigate how a variable of your choosing affects the process of osmosis. You may use the following list of questions to help you choose a variable to investigate, or you may generate an idea on your own.

- Is osmosis a temperature-dependent process?
- Do osmolarity and osmosis depend on the type of dissolved particle? For example, does it make a difference whether we use salt solutions or sugar solutions to test volume changes in the eggs?
- Does the age of the egg matter? Eggs lose water over time. Will this affect the isotonic point?
- Like cells, eggs exchange water with their environment at their surface. Is osmosis affected by egg size (surface area to volume relationships)?

2. In the spaces below, write your hypothesis, a brief rationale for your hypothesis, your experimental design, and your predictions for the outcome of your experiment.

☐ Hypothesis:

☐ Rationale:

☐ Experimental Design:

☐ Prediction:

Part B: Preparing Solutions

1. You will need to prepare at least four different percent (by volume) solutions to determine the isotonic point of your eggs. You will use dilutions of clear corn syrup with water to make solutions that can range anywhere between 0% (pure water) and 100% (pure corn syrup). Your group should start by deciding on the four different percent solutions to use for your experiment. Write your solution decisions in the spaces provided.

☐ Solution A _____%   ☐ Solution B _____%

☐ Solution C _____%   ☐ Solution D _____%

2. Now you'll need to calculate how much clear corn syrup and how much water to combine to make each solution. A 10% solution is one part corn syrup combined with nine parts water. If you are going to make 500 ml of a 10% solution, then you'll combine 0.1 X 500 ml, or 50 ml, of clear corn syrup with 0.9 X 500 ml, or 450, ml of water (see below). Use the following chart to calculate the amount of clear corn syrup and water you need to combine to make all four of your solutions.

EXAMPLE:

If you want 500 ml of a 10% clear corn syrup solution, you will need to combine:
10% or 0.1 X 500 ml = 50 ml clear corn syrup and 90% or 0.9 X 500 ml = 450 ml water

Your solutions:

To make 500 ml of a ______% solution, combine

______ X 500 ml = ________ ml syrup with ______ X 500 ml water

To make 500 ml of a ______% solution, combine

______ X 500 ml = ________ ml syrup with ______ X 500 ml water

To make 500 ml of a ______% solution, combine

______ X 500 ml = ________ ml syrup with ______ X 500 ml water

To make 500 ml of a ______% solution, combine

______ X 500 ml = ________ ml syrup with ______ X 500 ml water

Note: If your experimental procedure requires you to make solutions using other reagents, your instructor will provide instructions. You can make percent solutions using dry reagents. For example, to make 500 ml of a 10% NaCl solution, you would combine 50 g NaCl with water until you have a final volume of 500 ml.

Part C: Determining Changes in Egg Volume

☐ 1. Construct a table for recording your data or use the tables provided at the end of this section (one for control data and one for treatment). Record the initial weight of each egg and the percent solutions you are using in the tables.

☐ 2. Before submerging eggs in their respective solutions, discuss with your lab partner(s) how to stagger measurements. Hint: It is impossible to weigh all the eggs at the same time.

☐ 3. Place one egg into the first solution, start the timer, and soak the egg for 15 minutes. Repeat for the other solutions.

☐ 4. After soaking each egg for 15 minutes, remove it with a spoon and carefully dry it with a paper towel.

☐ 5. Weigh each egg and record the weight in the table; calculate differences in weight by subtracting the starting weights.

☐ 6. Return each egg to its solution and repeat step 5 after 30 minutes.

☐ 7. Return each egg to its solution and repeat step 5 after 45 minutes.

Control:								
	Solutions							
Egg Weight in Grams	A _____%	_____% minus starting weight	B _____%	_____% minus starting weight	C _____%	_____% minus starting weight	D _____%	_____% minus starting weight
Starting 0 min		N/A		N/A		N/A		N/A
15 min								
30 min								
45 min								

Treatment #1:								
	Solutions							
Egg Weight in Grams	A ____%	____% minus starting weight	B ____%	____% minus starting weight	C ____%	____% minus starting weight	D ____%	____% minus starting weight
Starting 0 min		N/A		N/A		N/A		N/A
15 min								
30 min								
45 min								

Treatment #2:								
	Solutions							
Egg Weight in Grams	A ____%	____% minus starting weight	B ____%	____% minus starting weight	C ____%	____% minus starting weight	D ____%	____% minus starting weight
Starting 0 min		N/A		N/A		N/A		N/A
15 min								
30 min								
45 min								

Data Display and Analysis

☐ 1. Calculate the amount of water gained or lost in each solution by subtracting the starting weight from its 15-, 30-, and 45-minute weights for each solution. A positive value indicates there has been a net gain of water over time, while a negative value indicates a net loss over time. Record values in the preceding table. If you were investigating the effect of some variable on the rate of osmosis, you will want to convert your data to a rate by dividing the weight gained or lost by the amount of time elapsed, or g/min.

☐ 2. Construct a graph or graphs which best illustrate the change in weight over time for the various solutions and conditions. For each treatment, put the results for all four solutions on the same graph for easier comparison.

Follow-up Discussion Questions

Review:

1. Summarize your observations and data.

2. Review the concepts of *hypotonic*, *hypertonic*, and *isotonic* and determine which term applied to the solutions used. Which solutions were hypertonic and which were isotonic or hypotonic relative to the fluid inside the eggs?

Interpretive:

3. Estimate the percent solution that is isotonic to the fluid in the egg in each case. Did it change or remain the same as a result of your treatment protocol?

4. Compare your results with those of other groups. What conclusions can be drawn about the process of osmosis and the factors that affect it?

5. How did your results compare to your predictions?

6. Relate the results of the lab exercise to osmosis within a cell or organism. Think of some scenarios in which cells or organisms might be exposed to changes in the osmolarity of their environment. For example, salmon migrate from seawater to freshwater to spawn. Predict what will happen to their cell volumes.

Reflective:

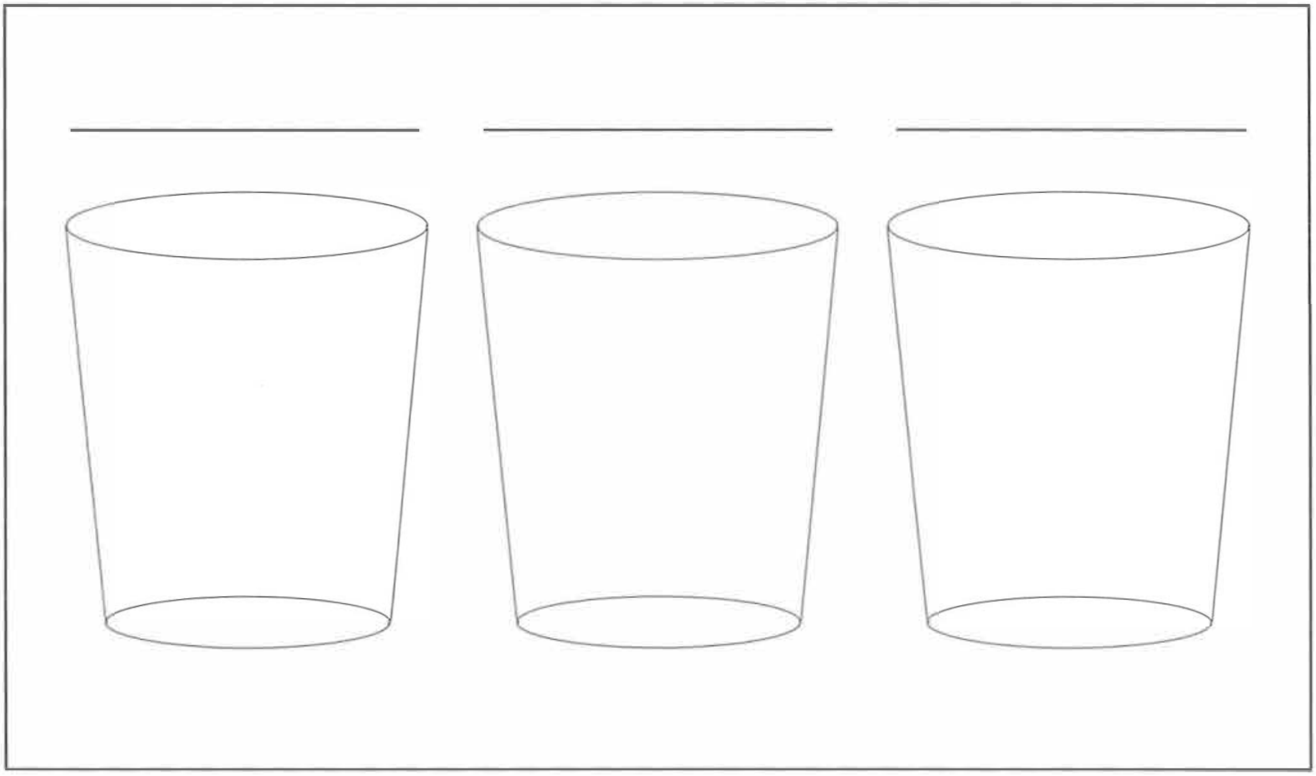
7. Determine sources of error for this lab.

8. Which aspect of the activity contributed most to your understanding of osmosis: group discussion? the hands-on manipulation?

9. Which aspects of the lab did you find most challenging? Explain.

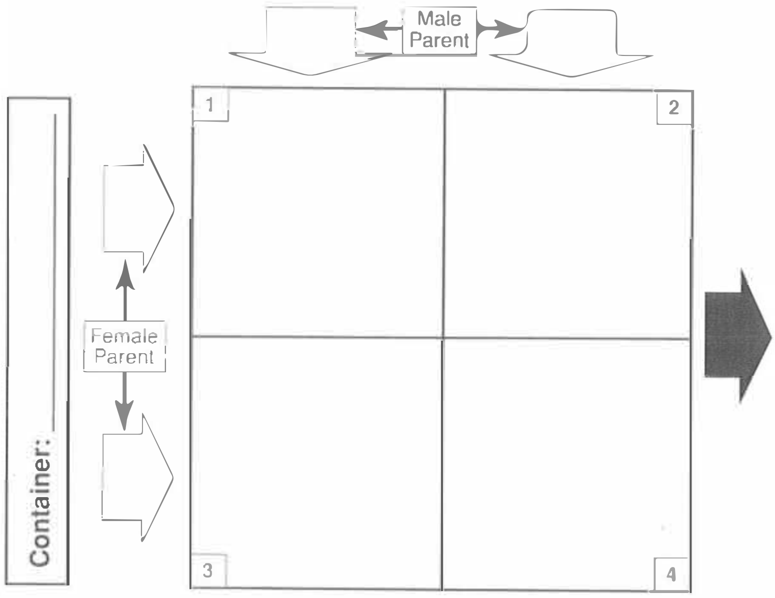
Mendelian Genetics

Part A: The Legos and Their Containers



Part B: Punnett Square Matings

Container: ____________________



(Each numbered box represents a potential offspring)

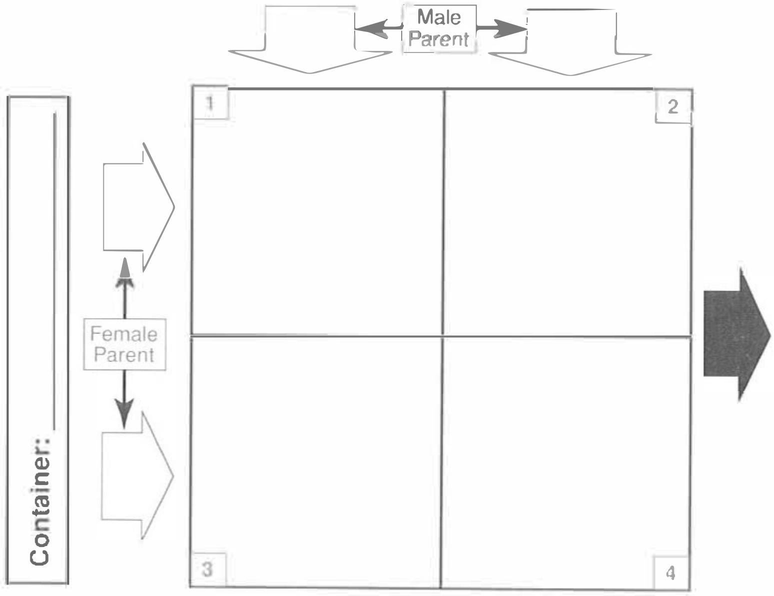
Analysis Questions

1. How many Lego/allele combinations are possible in offspring? ________
____

2. What is the probability of getting each combination? ________________

3. What color(s) will the offspring be?
____

Container: ____________________



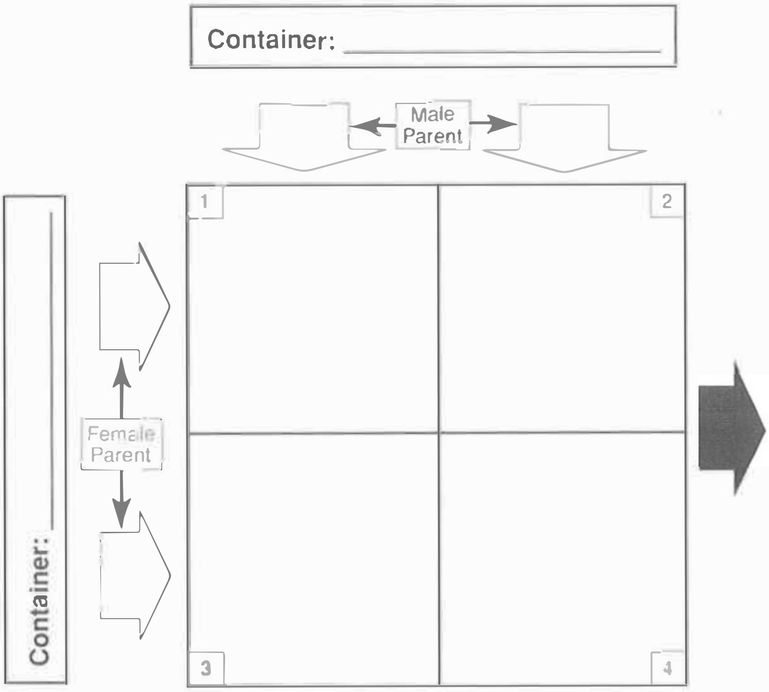
(Each numbered box represents a potential offspring)

Analysis Questions

1. How many Lego/allele combinations are possible in offspring? ________
____

2. What is the probability of getting each combination? ________________

3. What color(s) will the offspring be?
____



(Each numbered box represents a potential offspring)

Analysis Questions

1. How many Lego/allele combinations are possible in offspring? ______

______

2. What is the probability of getting each combination? ______

3. What color(s) will the offspring be?

______

Part C: Key Genetics Terminology

Genotype:

Phenotype:

Heterozygous:

Homozygous:

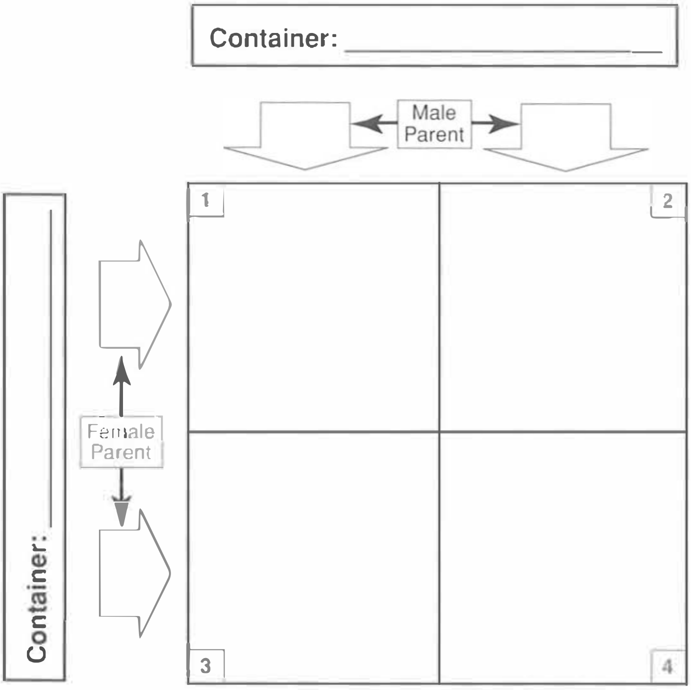
Dominant allele/dominance:

Recessive allele/recessiveness:

Phenotypic ratio:

Genotypic ratio:

Part D: Additional Punnett Square Matings



(Each numbered box represents a potential offspring)

Analysis Questions

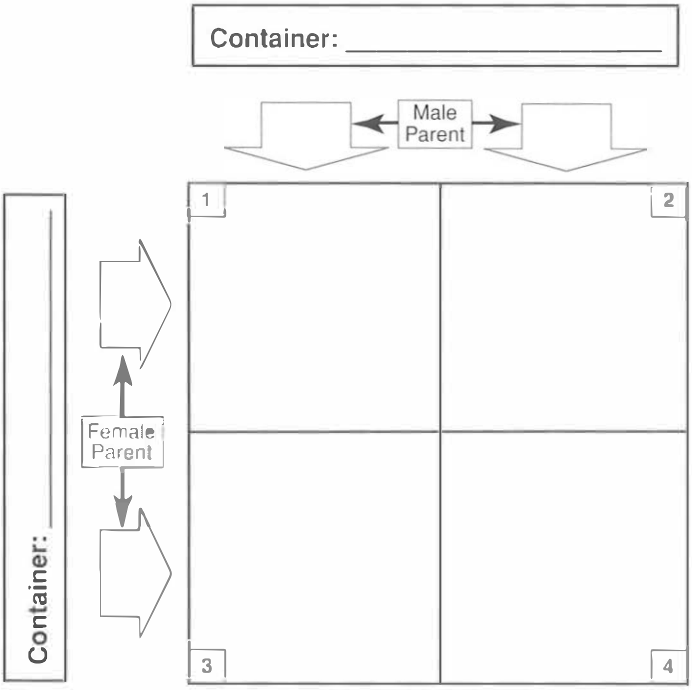
1. How many Lego/allele combinations are possible in offspring? ____

____

2. What is the probability of getting each combination? ____

3. What color(s) will the offspring be?

____



(Each numbered box represents a potential offspring)

Analysis Questions

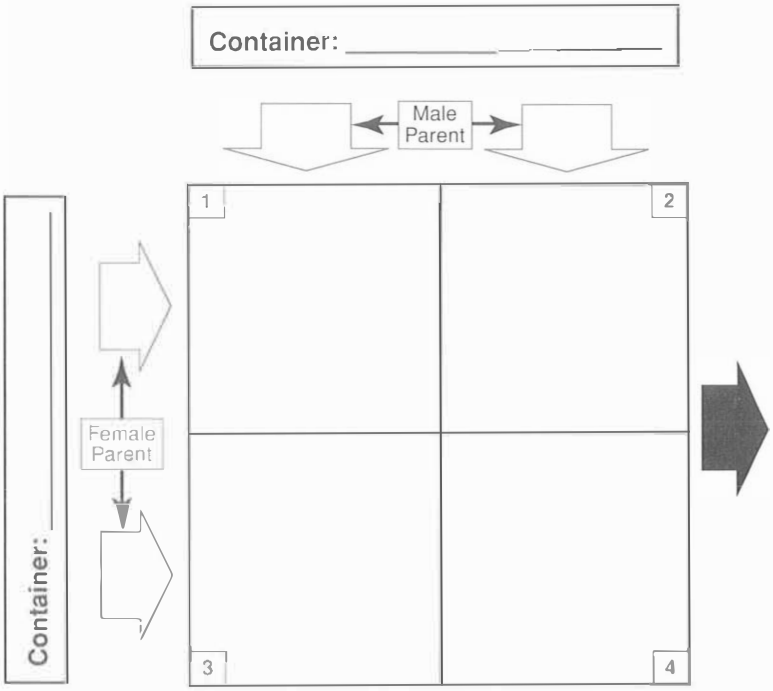
1. How many Lego/allele combinations are possible in offspring? ____

____

2. What is the probability of getting each combination? ____

3. What color(s) will the offspring be?

____



(Each numbered box represents a potential offspring)

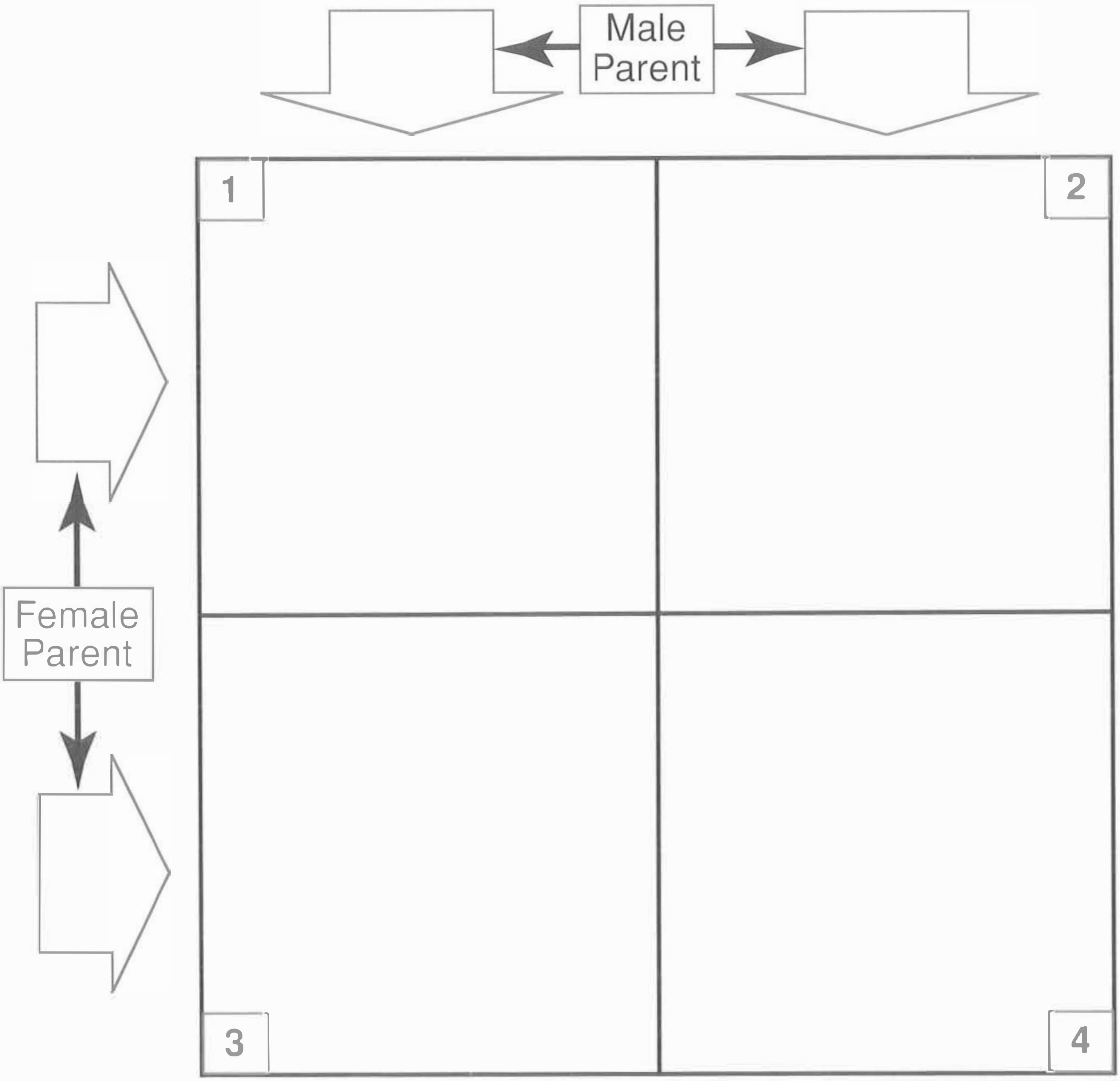
Analysis Questions

1. How many Lego/allele combinations are possible in offspring? ____________
____

2. What is the probability of getting each combination? ____________

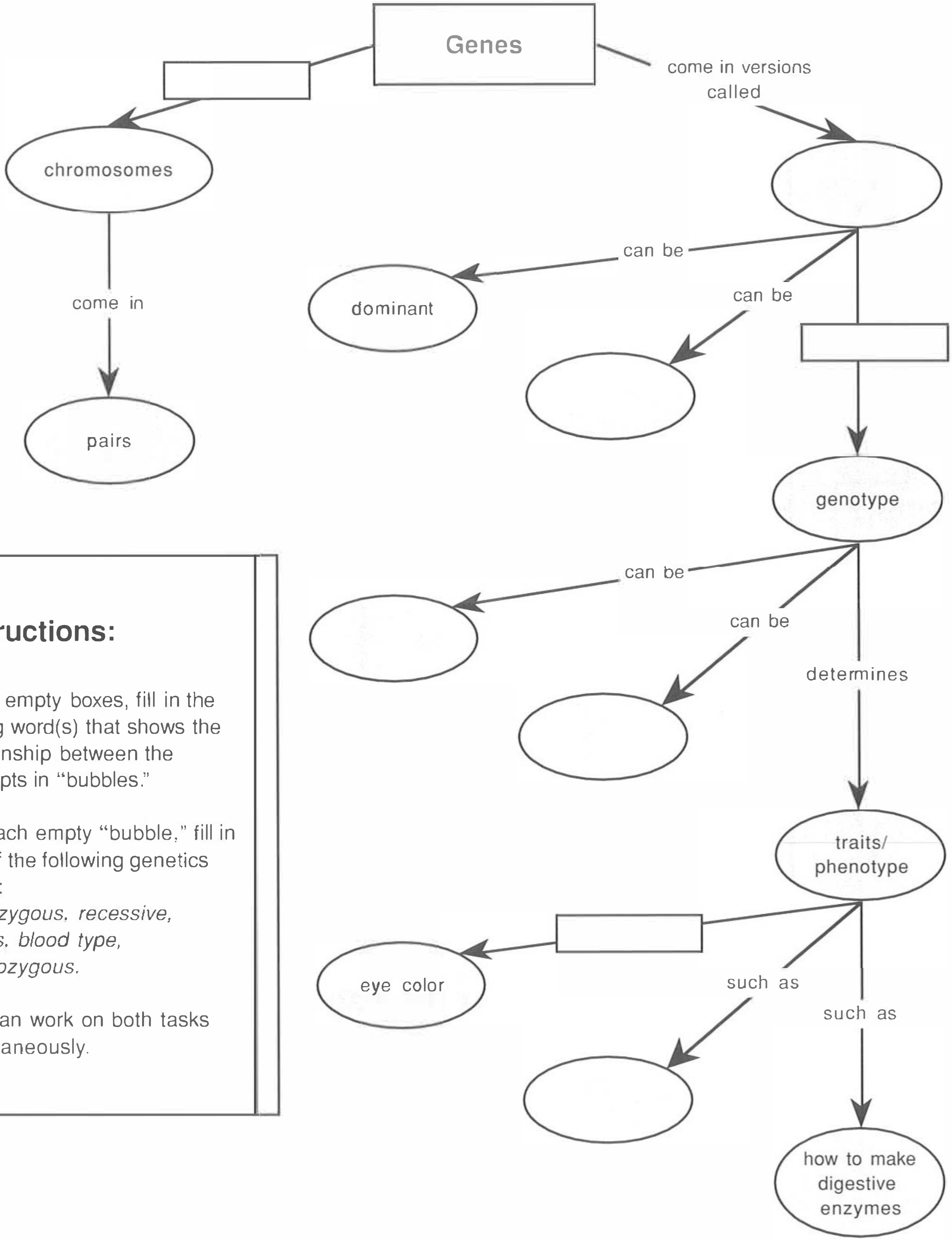
3. What color(s) will the offspring be?
____

Punnett Square Template



(Each numbered box represents a potential offspring)

Concept Map Assignment



Instructions:

In the empty boxes, fill in the linking word(s) that shows the relationship between the concepts in "bubbles."

For each empty "bubble," fill in one of the following genetics terms:
homozygous, recessive, alleles, blood type, heterozygous.

You can work on both tasks simultaneously.

Human Monogenic Traits

Activator/Connector

How many of you have known someone with polydactyly?
How many of you can roll your tongue?
How many of you have urine that smells "sulfury" after you eat asparagus?

Activity Purpose

In this lab, you will design a survey that collects data on some common human monogenic traits, and you will attempt to determine whether trait frequency is associated with trait dominance. Biologists typically use statistics to draw conclusions about larger populations based on studies of smaller groups. Part E of this activity provides the option of using statistics to draw conclusions about whether gender plays a role in the expression of monogenic traits.

General Background

A *monogenic trait* is a trait of an organism that is dictated by one gene on one chromosome. An example of a monogenic trait for humans is the disease cystic fibrosis. The single gene resides on Human Chromosome 7. While we can't easily detect the cystic fibrosis trait for the purposes of this study, we can easily detect several other monogenic traits in humans: tongue rolling capability, widow's peak, earlobes, index finger length, sensitivity to a bitter taste called PTC, handedness, mid-digital hair, and polydactyly. After learning about these monogenic traits, the class will design a survey to sample the frequency of these traits in the community.

Vocabulary

monogenics (monogenic traits), genotype, phenotype, heterozygous, recessive, dominance, sex-linked traits, sex-influenced traits, alleles, allele frequencies, gene pool

Learning Outcomes

After this lab activity, students will be able to:

Content

- Define a monogenic trait
- Distinguish the phenotypes for several human monogenic traits
- Differentiate between allele dominance and allele frequency
- Distinguish between sex-influenced traits and sex-linked traits (optional)

Inquiry Skills

- Identify some basic principles of survey design
- Calculate percentages
- Use clear language to accurately describe results from a data table
- Following data analysis, decide if a set of data supports a hypothesis
- Following statistical analysis, decide if a set of data supports a hypothesis (optional)

Activity Sequence

Day 1:

Preview activity, its purpose, background, and learning outcomes
Part A—Introduction to easily detected human monogenic traits
Part B—Design survey to answer investigative question
Part C—Perform survey and collect data (homework)

Day 2:

Part D—Share results of survey and calculate percentages
Part E—Optional statistical analysis (z-test)
Follow-up discussion questions

Materials

- Student handouts
- PTC paper and control paper
- Calculators

Procedure

Part A: Introduction to Monogenic Traits

☐ 1. In your own words, define the following terms:

Monogenic trait:

Polygenic trait:

☐ 2. **Investigative Question A:** Are phenotypes associated with the dominant allele generally found more frequently in a population than phenotypes associated with the recessive allele? What is your reasoning for your answer?

☐ 3. Use the following table to describe briefly the phenotype for each of the monogenic traits we will be studying. Your notes should be comprehensive enough so you will be able to recognize the traits when conducting your survey.

Trait	Phenotype 1	Dom. or Rec.?	Phenotype 2	Dom. or Rec.?
Tongue Rolling				
PTC Paper				
Widow's Peak				
Earlobes				
Index Finger Length				
Handedness				
Mid-Digital Hair				
Polydactyly				

☐ 4. Determine what phenotype you are for each trait in the table and circle the appropriate phenotype.

☐ 5. With the instructor's guidance, note in the table for each trait which phenotype is controlled by a dominant allele and which phenotype is controlled by a recessive allele.

☐ 6. What are some possible advantages or disadvantages to having any of these traits?

Part B: Survey Design

☐ Design a survey protocol for determining which phenotype for each trait is more common in the community. Be sure to include a gender component to the protocol.

Part C: Data Collection

☐ Use the Survey Data Collection Sheet on pages 10 and 11 to record the data from your survey in the community. Remember to enter data for males and females separately for use in Part E of this activity.

Part D: Data Analysis

☐ 1. Summarize your individual survey results in Table A: Summary of Individual Data on page 12.

☐ 2. Record the survey results from all class members in Table B: Composite Class Data for All Individuals Surveyed on page 12.

☐ 3. Compute and record percentages for all data collected and record them in Table B. For example, what percentage of individuals surveyed can roll their tongues? What percentage are right-handed?

Part E: Statistical Analysis (optional)

☐ 1. **Investigative Question B:** Is there any reason to believe that the frequency with which dominant traits are expressed differs between the genders? For example, do women express more dominant traits than men, or vice-versa? In the space below, provide a hypothesis and a rationale that relate to whether gender plays a role in the expression of dominant traits.

Hypothesis:

Rationale:

☐ 2. Record the number of dominant traits for each male and each female surveyed by all class members in Table C: Class Data: Number of Dominant Traits for Males and Females on pages 13 and 14.

☐ 3. Calculate the **mean** or average ($\bar{x}$) number of dominant traits expressed by all of the men surveyed as follows:

   a. Sum (or total) the number of dominant traits expressed by all males and enter in Table C at Σ_m (near end of table).

   b. Record the number of males surveyed at n_m in Table C.

   c. Divide the sum by the number of males surveyed to determine the mean number of dominant traits expressed per male: $\bar{x}_m = \Sigma_m / n_m$.

   d. Enter this value in Table C at $\bar{x}_m$.

☐ 4. Repeat steps 3.a through 3.d to calculate the mean number of dominant traits expressed per female (using the female data): $\bar{x}_f = \Sigma_f / n_f$. Record values in Table C.

☐ 5. Calculate the **deviation from the mean** for each male by subtracting the average number of dominant traits from each individual's number of dominant traits ($x_m - \bar{x}_m$). Enter each value in Table C.

☐ 6. Repeat step 5 for each female ($x_f - \bar{x}_f$). Enter values in Table C.

☐ 7. Calculate the **square of each deviation**, or ($x - \bar{x})^2$, for males and females and enter each value in Table C. Note that by squaring the deviations, we have eliminated any minus signs.

☐ 8. Using the data in Table C, calculate the **sum of squares,** or $\Sigma (x - \bar{x})^2$, for all of the males and for all of the females, and enter these values in Table D on page 15.

☐ 9. Divide the results of step 8 by (n – 1), the total number of males (or females) surveyed minus one, and enter in Table D.

☐ 10. Calculate the square root of each result from step 9 and enter it in Table D. You have just calculated s, or the **standard deviation**.

☐ 11. Transfer the values for n, or the total number of males and females surveyed, and $\bar{x}$, the average number of dominant traits expressed for the male and the female populations, from Table C to Table E on page 15.

☐ 12. Transfer the s values you calculated for Table D to Table E.

☐ 13. Finally, transfer s^2 values from Table D and record them in Table E. You have now successfully generated all of the variables you need to perform a ***z*-test** on your data to determine whether males differ significantly from females in their expression of certain autosomal dominant traits.

☐ 14. The formula for determining ***z*** is as follows:

$$z\ score = \frac{\left(\bar{x}_m - \bar{x}_f\right)}{\sqrt{\frac{s_m^2}{n_m} - \frac{s_f^2}{n_f}}}$$

Note: If you're unsure of how to start using this formula, follow the next steps:

- Calculate: $\frac{s_m^2}{n_m}$ and $\frac{s_f^2}{n_f}$
- Subtract: $\frac{s_m^2}{n_m}$ minus $\frac{s_f^2}{n_f}$
- Now take the square root of that number, and you will have the value of the denominator of the previous formula.
- To determine the numerator, subtract the average number of dominant traits expressed by females ($\bar{x}_f$) from the average number expressed by males ($\bar{x}_m$).
- Finally, divide the numerator by the denominator to obtain the ***z-score*** for your data. Write it in the space that follows.

z-score = ________________________________

If the *z-score* is greater than 1.96, then we can state with 95% certainty that the males and females surveyed differed in the number of dominant traits they expressed. However, it's also important to convey *how* these two populations differed. In this case, if the mean number of dominant traits for males was greater than the mean for females (or $\bar{x}_m > \bar{x}_f$), then we can state, "Males in our survey expressed a *significantly* greater number of dominant traits than did females." If the mean number of dominant traits for females is greater than that for males (or $\bar{x}_f > \bar{x}_m$), then we can state, "Females in our survey expressed a *significantly* greater number of dominant traits than did males."

If the *z-score* is less than 1.96, then we can state with 95% certainty that "the number of dominant traits expressed by males and females in our survey did not differ *significantly*."

15. State the results of your statistical analysis of the data.

Follow-up Discussion Questions

Review:

1. In general, how would you describe your results?

2. In this community, which of the two phenotypes for each of the monogenic traits surveyed was more common?

3. Are any of the phenotypes more common in women than they are in men?

Interpretive:

4. Now relate your findings to Investigative Question A, posed in Procedure Part A: *Are phenotypes associated with the dominant allele generally found more frequently in a population than phenotypes associated with the recessive allele?* Does the data support your original prediction and hypothesis? Why or why not? If not, how would you revise your hypothesis?

5. Now relate your findings to Investigative Question B, posed in Procedure Part E: *Is there any reason to think that the frequency of the traits under study will be different between the genders?* Does the data support your original prediction and hypothesis? Why or why not? If not, how would you revise your hypothesis?

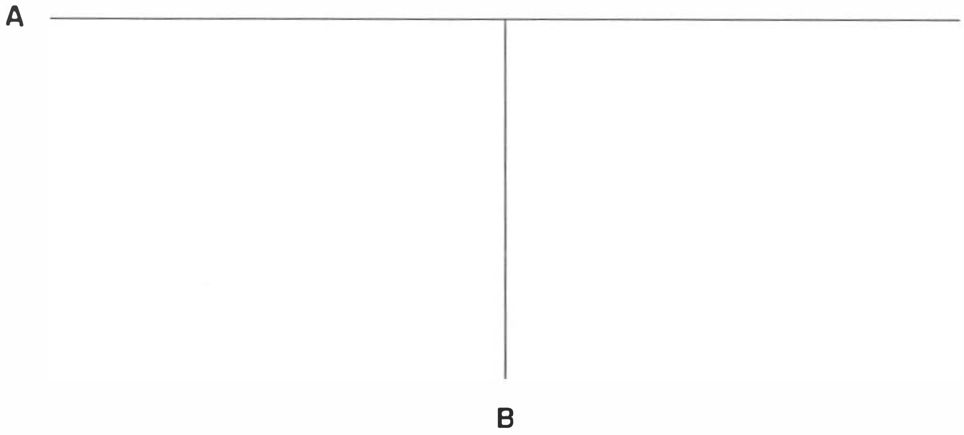
Reflective:

6. What was difficult for you in doing this activity?

7. What did you like about the activity?

8. What would you change?

TEMPLATE FOR MEASURING INDEX FINGER LENGTH PHENOTYPE



Instructions: Lay right hand on this grid so that the middle finger lies on Line B and the tip of the ring finger is in line with Line A. If the index finger lies below Line A, then the phenotype is "short index finger." If the index finger lies on or above Line A, then the phenotype is "long index finger."

SURVEY DATA COLLECTION SHEET

Name: ______________________________

Record whether each individual surveyed expressed the dominant or recessive trait for the eight traits listed below. Keep male and female data separate.

Male #1:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

Male #2:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

Male #3:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

Male #4:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

Male #5:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

Female #1:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

Female #2:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

Female #3:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

Female #4:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

Female #5:

Trait:	Tongue Rolling	PTC Paper	Widow's Peak	Earlobes	Index Finger Length	Handed-ness	Mid-Digital Hair	Poly-dactyly	Total #
Dominant									
Recessive									N/A

DATA ANALYSIS TABLES

Table A: Summary of Individual Data			
Trait	Number with Dominant Trait	Number with Recessive Trait	Total Number Surveyed
Tongue Rolling			
PTC Paper			
Widow's Peak			
Earlobes			
Index Finger Length			
Handedness			
Mid-Digital Hair			
Polydactyly			

Table B: Composite Class Data for All Individuals Surveyed					
Trait	Total Number Surveyed	Number with Dominant Trait	Number with Recessive Trait	Percent with Dominant Trait	Percent with Recessive Trait
Tongue Rolling					
PTC Paper					
Widow's Peak					
Earlobes					
Index Finger Length					
Handedness					
Mid-Digital Hair					
Polydactyly					

STATISTICAL ANALYSIS TABLES

Table C: Class Data: Number of Dominant Traits for Males and Females

	# dominant traits / male, or x_m	$(x_m - \bar{x})$	$(x_m - \bar{x})^2$		# dominant traits / female, or x_f	$(x_f - \bar{x})$	$(x_f - \bar{x})^2$
1				1			
2				2			
3				3			
4				4			
5				5			
6				6			
7				7			
8				8			
9				9			
10				10			
11				11			
12				12			
13				13			
14				14			
15				15			
16				16			
17				17			
18				18			
19				19			
20				20			
21				21			
22				22			
23				23			
24				24			
25				25			
26				26			
27				27			

Table C: Class Data: Number of Dominant Traits for Males and Females (continued)

	# dominant traits / male, or x_m	$(x_m - \bar{x})$	$(x_m - \bar{x})^2$		# dominant traits / female, or x_f	$(x_f - \bar{x})$	$(x_f - \bar{x})^2$
28				28			
29				29			
30				30			
31				31			
32				32			
33				33			
34				34			
35				35			
36				36			
37				37			
38				38			
39				39			
40				40			
41				41			
42				42			
43				43			
44				44			
45				45			
Σ_m		N/A	N/A	Σ_f		N/A	N/A
n_m		N/A	N/A	n_f		N/A	N/A
$\bar{x}_m$		N/A	N/A	$\bar{x}_f$		N/A	N/A

Table D: Standard Deviation			
	$\sum(x-\bar{x})^2$	$s^2=\frac{\sum(x-\bar{x})^2}{n-1}$	$s=\sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$
Males			
Females			

Table E: Z-Test Data				
	n	$\bar{x}$	s	s^2
Males				
Females				

INDEX