Preface

Scientific teaching has two meanings: it refers to the *science of teaching*, which implies approaching teaching with the same rigor that scientists bring to research, and the *teaching of science*, which suggests teaching science in a way that captures the essence of the scientific endeavor (Handelsman et al. 2004). The goal of this book is to provide principles, knowledge, and examples that will help scientists practice scientific teaching.

Chapter 1 explores scientific teaching as the science of teaching. This chapter provides background about the historical context of scientific teaching and proposes a framework that creates the basis for bringing the spirit of research to teaching, which involves setting, achieving, and evaluating teaching goals to maximize learning. This framework incorporates the concept of "backward design," according to which teaching goals and criteria for evaluating learning are set up before content and teaching methods are chosen.

Chapter 2 presents an overview of active learning. This chapter gives a summary about the biology of the brain and how it applies to learning in the classroom. In addition, this chapter integrates the philosophy and techniques of inquiry-based learning, group learning, student-centered learning, and cooperative learning. We offer a guide and examples for transforming passive lecture content into a vehicle for active learning.

Chapter 3 provides an overview of assessment. This chapter serves as a primer about the roles of assessment in scientific teaching—its role in the classroom as a means to foster learning and as a tool for evaluating the instruction itself. This chapter supplies tested examples of classroom assessment methods to evaluate student understanding and tools for making expectations clear.

Chapter 4 examines diversity. This chapter discusses the benefits and challenges of diversity in the classroom. We explore diversity in cognitive style and how to accommodate this diversity in the classroom. The latter part of the chapter considers the impact of unconscious bias on how we treat our students and discusses strategies to overcome bias and prejudice in the classroom.

Chapter 5 describes a framework for developing a teaching plan. This chapter puts backward design to work. We lay out a detailed sequence of steps to build effective teaching plans and examples of teachable units that were designed using these principles, and highlight learning models that help guide instructional design.

Chapter 6 presents strategies to effect institutional change. After instructors make changes in their own classrooms, they often want to extend the change to other instructors and disciplines. This chapter offers a conceptual framework and workshops for instigating change at the university level.

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Chapter 1

Scientific Teaching Defined

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Scientific Teaching Defined

What is "Scientific Teaching?"

Scientific teaching is the science of teaching and the teaching of science (Handelsman et al. 2004). The premise of scientific teaching is that science education will be improved if instructors approach teaching with the same rigor, creativity, and spirit of experimentation that is fundamental to research. It also posits that the teaching of science should be faithful to the true nature of science, capturing the process of discovery in the classroom.

Scientific teaching is needed because science is important. We do a disservice to our discipline and our students by reducing science education to a spontaneous, sometimes haphazard, process of delivering information with no attention to evidence either from the published literature or from our students about the validity of our methods. Scientific teaching employs methods whose effectiveness is supported by research; it questions students frequently to determine whether they are learning; and it depends on midcourse corrections in response to informal and formal assessments of learning. We simply cannot afford to deliver science education with ineffective methods and discover only when we grade exams, long after the actual teaching event, that our students largely missed or misunderstood the content. The rapid rate of expansion of many scientific frontiers places the onus on science educators to teach efficiently and effectively, assuring that students acquire a vast amount of knowledge and retain a good portion of it. Our students, whether they are biology majors or art history majors, should not complete their college education without understanding basic principles and facts about the world around them. Equally important, our students need to emerge with an understanding of the scientific process so they can understand the origins of scientific information and think critically about it, and sustain a lifelong curiosity about the world around them.

This book is designed to demystify the process of scientific teaching. The first four chapters explore the science of teaching, highlighting perspectives on learning and examples of teaching and assessment methods that can be translated directly into the classroom. Chapter 5 provides a framework for developing teaching plans that adhere to the principles of scientific teaching and guide students to an understanding of science that includes content, critical thinking, and experimental inquiry.

A framework for scientific teaching

Scientific teaching offers a natural framework for teaching that parallels our approach to research. Rather than allowing a last-minute, somewhat random approach to designing classes, building a framework according to scientific principles requires forethought, planning, and time. As researchers, we would never start designing an experiment without first identifying a question, hypothesis, or outcome. A researcher would never sit down and say, "First, I think I'll run a gel. Then, maybe I'll take a look at my sample under the light microscope. Maybe at the end of the day, I'll do some immunoprecipitations. Tomorrow I'll develop a hypothesis and decide what I want to find out about my organism." Sound silly? In effect, this is what many scientists do with regard to their teaching.

Scientific teaching requires that teaching be approached with an unremitting focus on outcomes. Instructors need to consider what they want their students to know, understand, and be able to do and work back from there. The good news is that once a sound framework is in place, filling in the details for each class session comes easily.

An ideal framework, proposed by Wiggins and McTighe (1998), is known as **backward design**. This book is based on a modified version of backward design and involves four steps:

1. **Identify the learning goals.** What will students will know, understand, and be able to do?
2. **Establish what criteria will be assessed.** How will students and instructors gauge progress toward the learning goals?
3. **Plan learning experiences and instruction.** What activities will engage a diversity of students in learning?
4. **Align and revise.** Do the activities and assessments engage students in achieving the learning goals and in gauging their progress toward the goals?

Backward Design is deceptively simple. It is familiar to scientists, because it is the process by which most experiments are planned, but it is the reverse of how most people conceive of their teaching. Identifying outcomes and the assessments that the instructor will use to determine whether the outcomes have been achieved *before* designing a teaching plan is a powerful way to focus attention on successful learning, rather than on teaching and covering content. The organization used in this book follows the principles of Backward Design.

Table 1.1 provides a simple format to summarize the content of a class period and organize the instructor's thinking about the principles of scientific teaching.

Table 1.1. A framework for scientific teaching.

			Alignment
What do I want students to know, understand, and be able to do?	How will I determine whether my students have met the learning goals? How will students assess their own learning?	What techniques will I use to engage a diverse group of students in active learning?	Do the activities and assessments engage students in achieving the learning goals and in gauging their progress toward the goals?

The following section outlines the steps for designing a teaching plan. These steps are expanded in subsequent chapters.

Guiding Questions

Passion for their disciplines often leads scientists to get lost in the details of the material they are teaching, and it helps to remember the larger context. Considering a few global questions when planning teaching helps to keep our students and their learning goals in mind. The guiding questions are divided into four topics. First, we ask whether teaching adheres to the principles of scientific teaching. Next, we propose guiding questions about three important themes in scientific teaching: assessment, active learning, and diversity. These questions offer a guide to individual instructors to become scientific teachers and also provide a basis for discussing teaching with colleagues.

The guiding questions are focused on the development of a **Teachable Unit**, which is defined as a cohesive set of material and activities focused on teaching a fundamental concept in biology. Teachable Units are typically intended to be taught in a few class sessions (perhaps three lectures or two labs, or some combination) but their size and depth can vary. These questions can be applied more broadly to the development of other instructional materials or teaching circumstances.

Guiding Questions for Scientific Teaching

Teaching Science

1. Do the goals of the Teachable Unit reflect the most important content in this topic?
2. Do the goals reflect the nature of science?
3. Do the assessments reflect the goals and determine the students' knowledge, abilities, and understanding?
4. Do the activities reflect authentic actions, behaviors, and processes of science?
5. Does the Teachable Unit include scientific content that is accurate, appropriate, and engaging?
6. Does the Teachable Unit provide goals, assessments, activities, and examples that are inclusive to diverse students?

The Science of Teaching

1. Are the assessments and activities aligned with the Teachable Unit's goals?
2. Are the Teachable Unit's goals aligned with your teaching goals?
3. Do the assessments provide you with data about your teaching?
4. Are the activities based on sound teaching principles?
5. Does your approach take into account the diverse range of students in the course?

Guiding Questions for Active Learning

Teaching Science

1. Consider the terms in this list. How are they the same? How are they different? How do or could you use them in the classroom?
   - Active learning
   - Inquiry-based learning
   - Student-centered learning
   - Group learning
   - Cooperative learning
   - Constructivism
2. How does the Teachable Unit engage students so that they are interested and motivated enough to be responsible for their own learning?
3. Does the Teachable Unit foster student-centered learning?
4. What is the overarching challenge, question, problem, or issue that the students will be asked to address?

The Science of Teaching

Discuss active learning in light of scientific teaching:

1. Does your Teachable Unit reflect the nature of science?
2. Does your Teachable Unit capture the rigor, iterative nature, and spirit of discovery characteristic of science at its best?

Guiding Questions for Assessment

Teaching Science

1. How do the assessment activities:
   a. motivate students to take responsibility for their own learning?
   b. help them to gauge their own progress?
   c. guide them to change behaviors in order to achieve the learning goals?
2. What opportunities will students have to gauge their progress toward the learning goals *during the learning process*?
3. What opportunities will students have to provide feedback to the instructor about their learning *during the learning process?*
4. How will you measure whether students have achieved the learning goals in the end?
5. Which assessments will be used for grading purposes, and which are designed only to promote learning? Do some overlap?
6. Is assessment aligned with learning goals? Can the assessment plan be simplified by consolidating assessment activities so that fewer activities assess multiple learning goals?

The Science of Teaching

1. How will you use the results of student assessment to guide your teaching decisions and planning?
2. What evidence do you have that students do (or don't) understand that topic the way it's been taught in the past?
3. What evidence do you have that your teaching is effective (or not)?
4. What evidence would convince you that a teaching strategy is effective? What is "effective?"
5. What evidence do you have that you teach according to your teaching philosophy?
6. Why do you think your Teachable Unit will be effective in at your institution? How will you know? How can you share those results?

Guiding Questions for Diversity

Teaching Science

1. How will the Teachable Unit encourage ALL students to be engaged?
2. What do we mean by ALL students?
3. How do these types of diversity affect teaching and learning?
4. What do you do in the classroom that might prohibit students from learning to the best of their abilities? Could the content or examples be construed as off-putting or attractive to particular students? How will this be addressed?
5. How can you anticipate who may not be engaged by a particular teaching strategy?

The Science of Teaching

1. How can you use the principles of scientific teaching to address issues of diversity?
2. Have you considered your audience in your approach?
3. How can your approach effectively reach the broadest audience?
4. How can you determine whether ALL of your students are learning?

Chapter 2

Active Learning

Chapter 2
Active Learning

This chapter integrates historic and current research on inquiry-based learning, group learning, student-centered learning, and cooperative learning and then presents examples of active learning techniques for biology courses and practical strategies for converting traditional lectures to vehicles for active learning.

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Practical Advice: Active Learning in Lecture[1]

Why active learning?

Involving students actively in the science classroom enhances understanding and retention and makes the classroom reflect the true nature of science. Large lectures and small discussions can be made active either with no technology or cost or with state-of-the-art classroom electronics. An important element of all the techniques described is that they can all be used as tools for assessment. Assessment and active learning converge, or perhaps are the same thing, because as soon as students become active, they—and the instructor—will discover what they know or are confused about. This type of assessment, threaded throughout the teaching process, is a key to good teaching because the instructor and the students monitor learning before an evaluative assessment, such as an exam.

Capturing the spirit of science in the classroom
Sharing the results of an experiment with peers in the laboratory, chatting with a colleague about a recent paper in *Science*, or learning a new experimental technique from a friend are common experiences for working scientists. Rarely is a new idea the product of a single mind. Scientists depend on each other to criticize ideas in seminars and reviews of manuscripts and research proposals. Participation in rigorous, open scientific debate is one of the most stimulating aspects of being a scientist. And yet introductory science courses rarely capture the spirit of dialogue that is characteristic of the scientific enterprise. Students often think of biology as a set of facts that come from a textbook, rather than from a dynamic process that involves experimentation and development and revision of ideas. Many students leave science because they think it is a collection of facts, not a process of probing for answers (Tobias 1990). Participation in a community of biologists is essential to understanding the process of scientific inquiry. Therefore, we must turn our introductory science classrooms into communities of scientists to teach what it really means to be a scientist.

[1] Adapted from Handelsman, Jo, Barbara Houser, and Helaine Kriegel. 2002. *Biology Brought to Life: A Guide to Teaching Students to Think Like Scientists* (Instructor Version) McGraw-Hill. ISBN 0-07-282389-5

Enhancing learning with active participation

Active learning is not a new concept—it is integral to the roots of epistemology articulated by Plato (1901). Socrates, engaging his disciples in group questioning and argument to develop their philosophical ideas, used a form of active learning, and it has endured as a way of learning in some cultures for generations (Dewey 1916, Haynes and Gebreyesus 1992, Jagers 1992, Swisher 1990). Early in the twentieth century when American students were schooled in a system based on authoritarian teaching and rote learning, John Dewey asserted the role of the learner and the learner's prior knowledge in the learning process, introducing his now-famous metaphor that students are not simply "empty vessels" to be filled by teachers (Dewey 1916). Dewey provided the blueprint for modern constructivist theory, which contends that learning must accommodate and build upon the experience of the learner, who actively integrates new knowledge into an existing framework. Constructivism asserts that each of us creates our own rules and explanations that we use to make sense of our experiences. Learning, therefore, is the process of adjusting our mental models to accommodate new experiences. Students assimilate new information by constructing scaffolds on which they can organize and retain facts and concepts (Ausubel 1963, Ausubel 2000). Teaching, in turn, needs to accommodate—indeed, augment—this process. Active participation in lectures helps students develop the habits of mind that drive science.

In biology, a number of studies show the benefits of active learning. For example, Dan Udovic at the University of Oregon taught the same biology course in a traditional passive lecture mode and in an active format, called "Workshop Biology" (Udovic et al. 2002). The differences in assessed learning were quite striking. In a comparison of performance on a test given before and after the course, the students in the Workshop Biology demonstrated significantly greater proficiency ($p<0.01$) than students in the traditional lecture course (Figure 2.1).

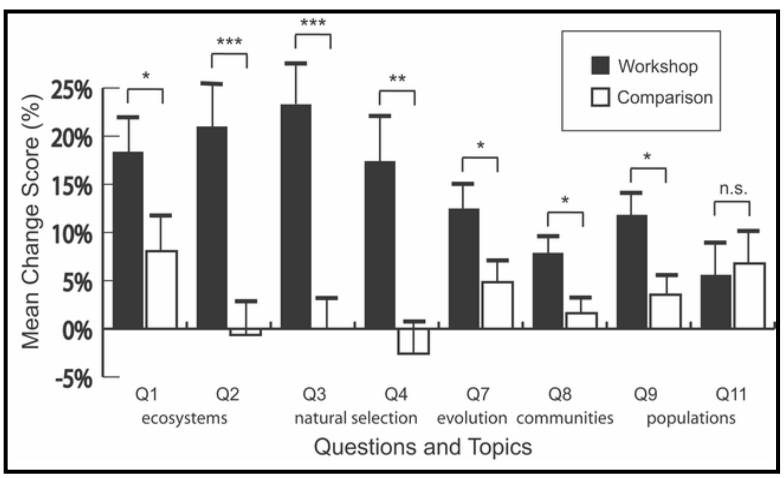

Figure 2.1 Mean change in scores from exams in workshop biology vs. traditional lecture. Error bars represent one standard error (*$p<0.05$; **$p<0.01$; ***$p<0.001$; n.s. $p>0.05$) (Udovic et al. 2002). Similar results have been achieved in other studies in biology teaching and other fields of science (Beichner et al. 1999, Ebert-May et al. 2003). Some consistent themes are: active engagement enhances learning and retention; active learning builds higher-order thinking skills; active learning reaches a diversity of students.

The power of group learning

Active learning can take many forms, including both individual and group work. A vast body of research indicates that learning is different in cooperative and competitive settings, and in groups or individual modes. In 1949, Columbia University professor Morton Deutsch evaluated the effects of cooperation and competition on the functioning of small groups (Deutsch 1949a, Deutsch 1949b). Deutsch defined cooperative and competitive groups according to basic differences in their goal structures. In cooperative groups, goals can be achieved by most or all group members; in competitive groups, goals can be achieved by some members but not by all. When he compared the two groups, Deutsch observed that the cooperative group scored higher on assessments of coordination of effort, obligation to participate, attentiveness to group members, diversity of contributions, subdivision of labor, understanding of communication, pressure to achieve, productivity per unit time, quality of product, and orderliness in the cooperative group.

Scientists often say that love of competition is a prerequisite to success in science, and therefore it is appropriate that our teaching methods capture the nature of competition. But one group of researchers, the Johnson brothers at the University of Minnesota, explored and exposed common societal myths about competition—that most human interaction in all societies is competitive; that the use of competition will increase the quality of a student's work; that competition enhances the capacity for adaptive problem-solving; that competition builds character; that students prefer competitive situations; and that competition builds self-confidence and self-esteem. Two decades of research by the Johnsons exploded a number of these myths, demonstrating that the success of even the most competitive activities in our culture, sports and warfare, require far more cooperative than competitive interactions. They showed repeatedly that cooperative formats foster learning in diverse settings (Johnson et al. 1978, Johnson and Johnson 1985). Evidence has accumulated on the effectiveness of cooperative learning in science. Cooperative learning methods have been applied in the physical sciences (Beichner et al. 1999, Smith et al. 1991), mathematics (Dees 1991, Duren and Cherrington 1992), and biology (Ebert-May et al. 2003, Lazarowitz et al. 1988, Okebukola 1986a, Okebukola 1986b).

A continuing point of controversy surrounding cooperative learning is whether high-ability students in heterogeneous cooperative groups are penalized by working with low-ability students. Rewey and her colleagues (Rewey et al. 1992) showed that cooperative learning can heighten learning among low-ability undergraduate students without diminishing the performance of high-ability students. Physicist Bob Beichner showed in a national study of physics classrooms at three universities that all students benefited from a cooperative, active classroom compared to a traditional lecture, but high-achieving students benefited the most (Beichner et al. 1999).

Enhancing human diversity in science

Classrooms that respect, value, and include the contributions of all students will be more likely to attract and retain women and minorities, who often express a sense of alienation, exclusion, and disenfranchisement in the traditional science classroom (Hewitt and Seymour 1997, Little Soldier 1989, Okebukola 1986a). We should be challenging ourselves to interest women and minorities in science, to attract them to our courses, and to provide them with a positive environment, the necessary stimulation, and the feeling that they are valued members of our educational community. Many people do not learn best in the traditional competitive, fact-oriented classroom, but this learning environment appears to be less effective, on average, for women than for men. Active learning in the science classroom can be readily designed to include women as active contributors within a learning environment of interaction and collaboration. Moreover, teachers who have applied these methods have found that what works well for women also works for many men, minorities, and students who feel alienated and disempowered in the science classroom (Rosser 1990).

Formats for Active Learning

Many teachers would like to build an active classroom but lack specific strategies to confront the everyday situations and surprises that arise in the classroom. Teachers comment that they would like to involve the students in more discussion, but the students simply will not talk. Other teachers are afraid of correcting students for fear the students will withdraw. Still others have trouble overcoming their students' feelings of not belonging in science. The following are a few proven tips and tools to engage students and help teachers deal confidently with the daily management of the classroom.

Group problem solving
The simplest method to engage students actively in a lecture is to present a problem to the class as a whole, instruct the students to consult with the students sitting on either side of them in groups of three for three to five minutes and then report to the entire class. Each group is then asked to report the results of their group's consultation and the results are recorded on the blackboard. In large classes, the process can be shortened by asking for answers that differ from those already reported after the first few groups report. If this approach is used, it is essential to start the reporting process with groups from a different part of the classroom each time cooperative learning is used so that all groups have the opportunity to report their results over the course of the semester.

A common version of group problem solving is known as "think-pair-share." Students first think individually for a minute, then share their ideas briefly with a partner and discuss. Finally, students share their collective answers with the larger class.

Electronic audience response systems
A technological development that has catapulted active learning into common use is the advent of "clickers"—electronic key pads into which students enter answers to a question. Through either infrared or radio waves, their answers are transmitted to a central receiver that is connected to a computer that calculates and displays the frequency distribution of the answers. These can be projected for everyone to see. Clickers provide immediate feedback to the instructor and students about the learning that has occurred. They offer the opportunity to test understanding before and after an explanation or exercise, enabling the students to assess their own learning.

If instructors plan to use clickers, they must be sure to learn the system well before using it in the classroom. This technology is still new and students tend to be enthusiastic about it when it works, but impatient when there are bugs to be worked out (Hatch et al. 2005).

Group exams

One of the most surprising uses of cooperative learning for many teachers is group exams. It is surprising because most of us have been taught that exams must be individual, competitive experiences to measure learning. If, however, our goal is to *promote* learning, instead of just measuring it, we must consider the value of group exams. Group exams are most effective with open-ended, complex questions that do not have right or wrong answers. The group process, interactions among students, and vigorous debate are intensified by an exam structure and the grade associated with it. These can be used to generate creative ideas and build the critical and logical thinking skills needed for biology. Our own experience and that reported by others (Duren and Cherrington 1992, Johnson and Johnson 1975) shows that students are willing to tackle much more difficult problems in groups than they will attempt individually. We find that students respond best to being required to work with a group (we ask for a list of their group members) but then to generate a written answer individually for which they receive an individual grade. This approach capitalizes on both group process and pride in individual accomplishment.

One-minute questions

Asking students to write short answers to questions at the end of class offers students an active role in learning and a quick way to assess learning. Because the answers to the questions are short (short enough to fit on a 3 x 5 inch card), they provide a way for students to gain regular writing practice without adding a huge reading burden for the instructor.

Class routine can be established so that students pick up any class handouts and an index card on their way into class. They drop off their index cards in boxes marked with their lab section number on the way out of class. Whether or not the cards are graded, the students should be asked to put their names on them to encourage accountability. Some questions that stimulate the students to reflect on their learning are:

- What concept presented in class this week was difficult for you?
- What was the key concept in today's lecture?
- What else would you like to know about today's topic?

The answers to these questions can be illuminating to both students and teachers. The simple act of reflecting on and writing down the answer may lead students to realize that they should review that concept or see the instructor for help. A large number of students citing the same point of confusion may likewise lead the instructor to recognize the need to return to the concept during the next class meeting.

One-minute questions can encourage critical thinking and show students the relevance of biology and its connections to their everyday lives. Some questions that can develop self-awareness and critical thinking skills include:

- Describe the connection between the content of today's lecture and your life outside the classroom.

- Describe how your own personal bias, shaped by your background, ethnic origins, culture, experience, religion, education, or gender might affect your interpretation of the material presented today.

Strip sequence

A class activity to strengthen students' logical thinking processes and test understanding of biological or physical processes is the strip sequence. Step-by-step processes lend themselves well to this technique, but other material can also be used. Give students the steps in a process on strips of paper (or the virtual equivalent) that are jumbled (Figure 2.2). The challenge for the students in class is to work together to reconstruct the proper sequence. As with concept mapping, making logical connections helps the students dissect and reconstruct the process, improving understanding.

Figure 2.2. Strip sequence on gene expression

Cut into strips on lines, mix the strips, and instruct students to reassemble them in the correct order.

The first step in process of gene expression is transcription.
In this step, DNA is used as the template for synthesis of RNA (mRNA).
Base pairing between one strand of DNA and RNA bases, following the rules of base complementarity, defines the base sequence of the mRNA.
The enzyme RNA polymerase is required for mRNA synthesis.
In the next step, known as translation, mRNA bases pair with transfer RNA molecules (tRNA).
Each mRNA contains many 3-base units called codons; each tRNA has a unique 3-base unit called an anticodon.
Each tRNA carries a particular amino acid.
As the tRNAs line up along the mRNA in the order defined by codon/anticodon recognition, they define the sequence of amino acids in the protein.
The enzyme peptidyl transferase detaches the amino acids from their tRNAs and links them together to form a protein.
A string of amino acids makes up a protein, and proteins give an organism its distinguishing characteristics.

Concept mapping

Concept maps are graphic representations of the relationships between concepts. Concept maps can be drawn by students individually or in groups following these steps:

- Identify the key words, phrases, and notions of the concepts to be mapped.
- Enclose those key pieces in circles or boxes.
- Connect the ideas with lines or arrows and any brief linking words necessary to make the relationship between the parts clear.

One common approach to concept mapping is to give students pieces of a potential map and have them conceptualize the relationship between ideas and lay the pieces out. Most concepts are captured in the lines that connect items, so if students can explain the lines, they usually have a good grasp of the concept (Figure 2.3).

Since they were first developed in 1972 at Cornell University, concept maps have been shown repeatedly to enhance learning and development of higher-order thinking skills. Concept maps or other techniques that require students to reformat material are essential elements of a classroom that reaches diverse learners because in reformatting, individual students construct a framework that makes sense to them. To do so, they must grapple with the material and understand it. Students should have the opportunity to try out different formats and choose the format that suits both the material and their own learning styles.

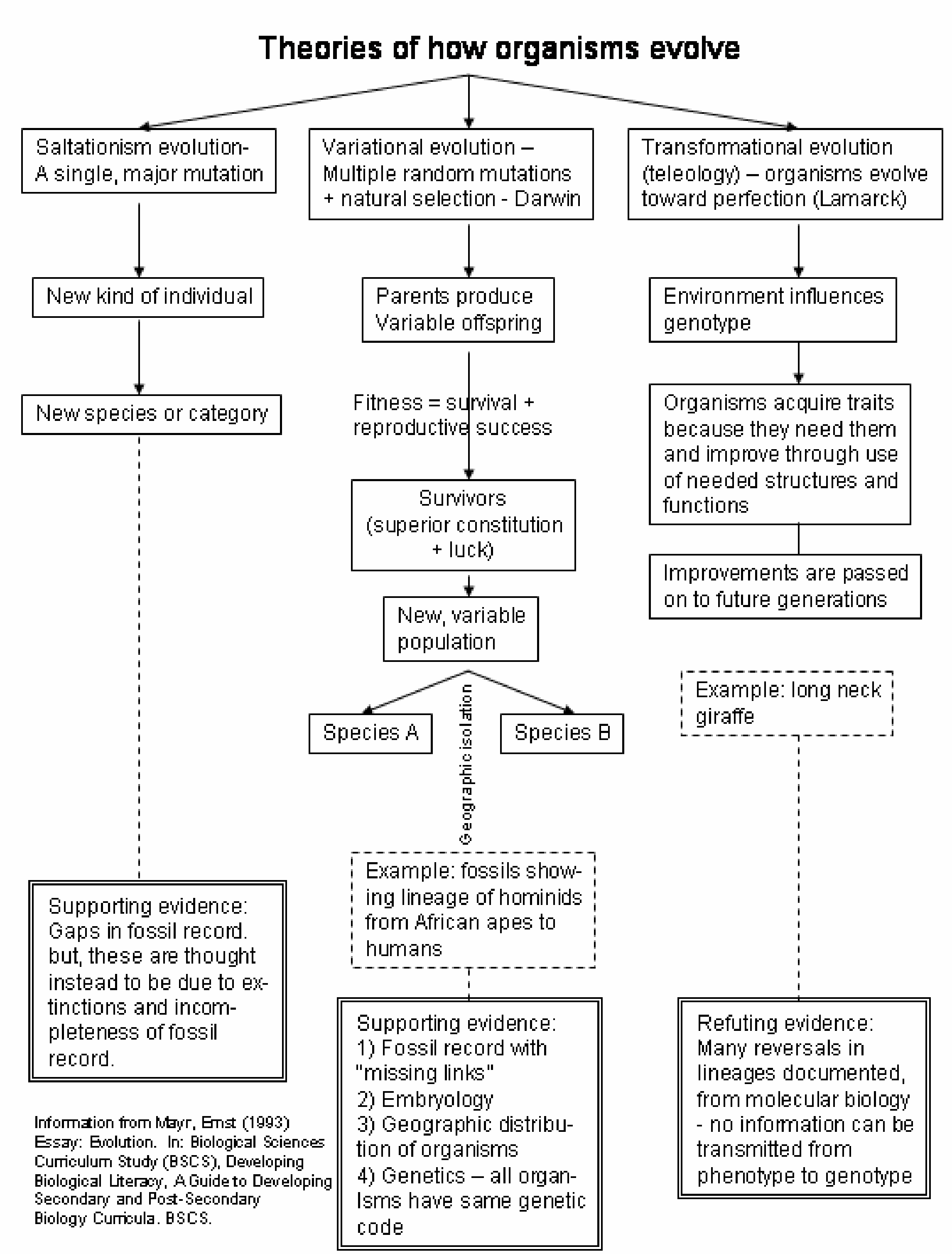

Figure 2.3. Concept map about evolution

Content for Active Learning Exercises

As instructors search for the part of the lecture to provide the basis for active learning, two things should be kept in mind. First, they should choose content that is important. Second, they must remember that every scientific fact was once a question, so anything in science can form the basis for active, inquiry-based learning. Some examples are shown in Table 2.1.

Table 2.1. Conversion of lecture material from passive to active.

Passive Lecture	Active Lecture
Every cell in an organism has the same DNA but different genes are expressed at different times and under various conditions. This is called gene expression.	If every cell in a plant has the same DNA, how can different parts of the plant look different? Work with a neighbor to generate a hypothesis.
Different parts of your body can do different things. For example, your hand has fine motor skills and your leg does not. This is due to different motor units.	Describe how the movements of your hand and leg differ. What do these differences suggest about the motor units in your hand compared to your leg? Work together to draw these two motor units.
Complementary base pairing is key to the mechanism of DNA replication.	What do you know about the structure of DNA that suggests a mechanism for replication? Think about it for a minute and then discuss with your neighbor.
Many people have concerns about genetically modified organisms. Some of these are well-founded and others are not. You have to decide for yourself.	Let's split the class into two groups. The left half of the room will brainstorm about the potential of genetically modified organisms to be used for beneficial purposes and the right half will discuss possible harm they could cause. Then we will have a debate.
Based on the data shown in this slide, researchers concluded the following:	Let's look at the data from the experiment I just described. Which of the following conclusions can you draw from these data? Let's take a vote and then discuss it.

The scientific method
Active learning exercises conducted individually or in groups are effective ways to reinforce application of the scientific method. Students can be presented with an observation about the natural world and then asked to confer in small groups to develop hypotheses that would explain it. Similarly, they can be asked to design an experiment to test a certain hypothesis or interpret experimental data.

Brainstorming
Presenting a broad, open-ended problem for the whole class to discuss and solve as a group is an effective way to introduce a new topic, engage students, and probe their prior knowledge. This exercise works especially well in a lecture setting and has the advantage of requiring little advance preparation time and no supplies or materials. The ideas generated by the students can serve as the basis for future lectures, which both contributes to the depth of learning in the class and gives students a sense of contributing substantively to the course content.

Some examples of collective brainstorming challenges are:

- Imagine you are a cell. What are your greatest challenges?
- Suggest new uses for genetic engineering in medicine or agriculture.
- Think of some examples of natural selection.
- What are the similarities or differences between . . . and . . .?

Decision making

Acquiring the power to make decisions that affect the lives of others and being held accountable for those decisions is a strong inducement to ask questions and to learn and evaluate facts about an issue. Ask students to imagine that they are policy-makers who must make tough decisions that require scientific information. The desire to appear responsible and rational will induce them to become experts on the issue, which will require learning information, thinking critically, and developing a creative solution.

Some examples of the types of decisions students can be asked to make are:

- You are the director of the antibiotic discovery unit in a major pharmaceutical company and you are asked to develop a five-year plan to develop new antibiotics. You are told that the plan will be funded only if you can convince your managers that you will be able to develop five new drugs with entirely new modes of action. Can you do it? What is your plan and how will you defend it?

- You are the U.S. Secretary of the Interior. You must decide whether or not to save the old forests of the Northwest and thereby preserve or destroy the biological diversity of the region. To save the forests, you must reduce or eliminate logging there, thus alienating the powerful lumber industry, causing unemployment, and severely affecting the economy of the region. What will be your policy? Why? How will you mitigate the social and environmental impacts of your policy?

- You are the head of a major blood bank, and there is a worldwide blood shortage. You are offered a shipment of blood that might be contaminated with a new retrovirus that has not been well studied. Will you allow the blood to be used? Why? What would you like to know before you make your decision?

- You are the Executive Director of the National Pesticide-Free Food Network. You hear that a chemical company is about to register a new fungicide. The fungicide reduces accumulation of aflatoxin, a highly carcinogenic toxin produced by a fungus that often grows on peanuts. You must decide whether your group should protest the use of the fungicide on peanuts. What questions will you ask and what process will you use to decide whether or not to fight the use of the fungicide?

Classroom Management

Start early

It is important to set the tone early in the semester. If the students receive the clear message that they are expected to be active members of the classroom, and if they perceive immediately that their ideas shape the classroom, then a community spirit will naturally follow.

Start simple

The first time instructors attempt to elicit thoughts from the students, they should try something simple, open-ended, or personal. Students may be afraid of being wrong or convinced that they know nothing about the subject if this is their first science course. If the first question they are asked is hard or has only one right answer that they may not know, they may not be eager to participate. The challenging questions should be saved for later when the students have more confidence or have learned that it is acceptable to be wrong. The first question could be something that makes a connection between the course and the rest of their lives. Some examples are:

- How does science affect your life?
- Describe something you would like to understand about the biological world.
- What issues facing the world today involve science and technology?
- What do you hope to learn in this course?

Try having groups set objectives for the course and report back to the entire class. Someone can be designated to record the list and return to it every few weeks with the class to determine whether the students' objectives are being met and whether new objectives have emerged.

Make it personal

Students strive harder and achieve higher standards if they are thought of as individuals and not just identification numbers. It can be difficult in large introductory courses to make personal contact with students, but a few tricks can help. If possible, take pictures of the students in groups with name cards on and learn as many names as possible. Call on even a few students in class by name; the classroom will have a more personal feel and the students will feel more committed to the class. Alternatively, when the students speak in class, ask them to say their names or hold up file folders with their names written in large letters. Then their ideas can be referred to with the students' names attached. Students hearing an instructor say, "as Heather pointed out," will develop pride in their ideas and a sense of being valued as members of a scientific community, which are important ingredients in maintaining active engagement.

Even if it is impossible to remember all of the students' names, let them know that they are noticed by addressing individuals with questions or comments. Chat with a few of them individually for a minute before each class, stop certain students and comment if they were not in class or were sitting in a different seat last time, or ask a student after class whether something said in lecture was clear and understandable. These actions are easy, require little time, preparation, or follow-up but have a powerful impact on the willingness of students to participate in a class. Students are often astonished that a teacher would care about them and their opinions.

Showing that scientists care about people and their ideas will make science seem more human and interesting to them.

Take risks

Sometimes students simply will not respond to a request for ideas. They may be too inhibited or they may not quite understand the material or the question asked. Often, gridlock can be broken by proposing an idea for the students to analyze or evaluate. Propose an obviously silly experiment and ask the students if it is going in the right direction. For example, if students have been asked to design an experiment to learn about the proteins in muscle cells, suggest starting with grinding up a liver and ask them if that is the right place to start and why. This approach can be humorous, but it serves the much deeper purpose of having the students realize that they know something about the topic at hand even if it is simply that the liver is not a great source of muscle cells. It is also valuable for students to learn to criticize ideas from any source, including the instructor.

Feedback

One of the simplest approaches to promoting participation is to be encouraging. This does not mean patting the students on the head and accepting their ideas without scrutiny. The key is to validate them as people while honestly evaluating their ideas and challenging them to evaluate their own and others' ideas. Students respond powerfully to trivial comments. Simply saying, "Good question!" before answering a question can put students at ease and encourage them to ask questions freely. It is important to avoid words and behavior that make students clam up. Using harsh phrases such as "You would know the answer to that if you had done the reading" or making jokes about a particular student's grade in front of the class is bound to make students hesitant about contributing to the class. Instructors often don't realize how offhand comments or jokes can affect the engagement of students in the class.

Dealing with "wrong"

One of the advantages of an active classroom community is that misconceptions are likely to be revealed quickly because most active teaching methods also function as assessment instruments. The power of this approach is that misconceptions can be dealt with immediately in class, instead of after an exam. It is essential that misconceptions be corrected so that they are not incorporated into students' thinking about the problem. However, students who have expressed wrong ideas have exposed themselves by sharing their ideas with the class, and it is important not to embarrass them or make them feel personally attacked. In managing an active classroom, it is essential to keep criticism of ideas separate from criticisms of people. In fact, the student who brings up an idea that is simply wrong according to current scientific knowledge may do a great service for the class and can be supported for doing so. By thanking the student for being brave enough to volunteer the idea, the teacher can provide personal support and respect for the person while making absolutely sure the idea is thoroughly evaluated and corrected. It may be possible to show the merits of the idea while correcting it. It may have historical value (if one of our students believes it, there was probably once a debate in which some great biologist defended the idea), it may be instructive as a contrast to the right idea, or it may simply be a common misconception that needs to be dispelled. A combination of approaches can be used to defuse the embarrassment of being wrong and to ensure that the correct information or idea is firmly established.

For example, let us imagine that a student named Horton states that proteins are the universal hereditary material. Hearing this, most teachers would panic and wonder what they did wrong to instill such a wrong-headed idea, but once the panic subsides, the teacher could use a number of approaches to arrive at the concept that nucleic acids are the hereditary material in biology. First, the other students might be asked if they agree with Horton's statement. This approach encourages the students to be critical of each others' ideas and provides the opportunity for Horton to be corrected by a peer instead of by the teacher, which may be less intimidating to him. If the other students do not correct the idea, then make the point that this is clearly a widely held misconception and it is a good thing Horton brought it up. This shows support for Horton and calls attention to the fact that many of the other students probably need to learn some information that is about to be presented. Whether a student or the teacher corrects the misconception, Horton's pride can be protected by discussing the fact that although all current evidence shows that proteins are *not* the universal hereditary material, there was a substantive debate about the chemical nature of hereditary material involving many great biologists in the early part of the twentieth century. Finally, Horton or anyone else in the class can be invited to imagine why nucleic acids might make better hereditary material than proteins, or how cells would function differently in transmission or expression of genes if genes were proteins. This takes the emphasis off the "wrongness" of Horton's idea and turns it instead into the basis for a creative, educational exercise. Thanking Horton in or after class for contributing the spark for this discussion makes it clear that a part of science—indeed an essential part—is experimenting with ideas and using discussion to arrive at a correct answer.

Maintain control and high standards

It is important to maintain control and insist on high standards of thought and behavior. Don't let a few students dominate or let the class become a free-for-all. Never let students expect that they can present sloppy or wrong ideas without being challenged. Make two things absolutely clear: in the classroom every idea will be rigorously evaluated, and it is okay to be wrong.

Ethics of group work

Encouraging or requiring group work will act as an invitation to some students to cheat, perhaps by copying another student's assignment, using lab results from an experiment they did not perform, or simply by not contributing to the group effort. The best method to prevent this is to make expectations clear. Cooperative work provides the substance for useful discussions about ethics in science, giving and sharing credit, and the difference between fair exchange and theft or exploitation. To prevent abuses of the system, the rules should be made explicit by being written down in course handouts. A separate handout on ethical conduct, explaining what is acceptable and what is not, is very much appreciated by students. The instructor should consider asking students to sign a contract for ethical conduct that states the requirements of the classroom (see Figure 2.4). Committing in writing to uphold ethical standards is probably enough to prevent most students from cheating. If instructors find that students cheat, they shouldn't give up on these methods—the same teaching methods that made the class vulnerable to misconduct by a few, enhances learning for many students.

Figure 2.4. Sample contract that states classroom expectations for ethical conduct.

Expectations for Students Participating in a Cooperative Classroom

Learning in a cooperative environment should be stimulating, demanding, and fair. Because this approach to learning is different from the competitive classroom structure that many other courses are based on, it is important for us to be clear about mutual expectations. Below are my expectations for students in this class. This set of expectations is intended to maximize debate and exchange of ideas in an atmosphere of mutual respect while preserving individual ownership of ideas and written words. If you feel you do not understand or cannot agree to these expectations, you should discuss this with your instructor and classmates.

1. Students are expected to work cooperatively with other members of the class and show respect for the ideas and contributions of other people.

2. When working as part of a group, students should strive to be good contributors to the group, to listen to others in the group and try not to dominate, and to recognize the contributions of others. Students should try to ensure that everyone in the group makes a contribution, and recognize that everyone contributes in different ways to a group process.

3. Students should conduct experiments, discuss group exams, and develop projects as part of a group, but write lab reports, exams, and papers alone and not copy from anyone else. If you use material from published sources, you must provide appropriate attribution.

I have read and understood the expectations of students in this class. If I am uncertain about appropriate behavior in the class I will ask one of the instructors for clarification.

Signed,

____

____

Please print your name here

Keep one copy for yourself and return the other copy to your TA.

Chapter 3

Assessment

Chapter 3
Assessment

This chapter explores the role of assessment in "enGauging" students. The term "enGauging" captures the spirit of assessment that is so much richer than testing. Students who are enGauged are simultaneously ***engaged*** in learning—responsible and motivated to learn—and able to ***gauge*** their own progress toward the learning goals. This chapter describes the essential features of assessment, provides examples for college biology courses, and offers suggestions for using assessment results as feedback that guides teaching and learning.

Assessment Defined

"Assessment is more than grades . . . it is feedback for students and instructors . . . and it drives student learning" (National Institute for Science Education 1999). Many instructors know intuitively that assessment is integral to teaching—that students learn from preparing for and taking exams. The philosophy of this chapter is based on that knowledge and takes it a step further. If our students learn from taking exams, and we discover what they have learned by grading the exams, then why wait for the exam to give an exam? Assessment in its broadest sense is a way to integrate into the learning process the learning achievements from assignments typically used for grading purposes. Done well, assessment fosters learning and enables both students and instructor to identify gaps, confusion, and mistakes, and lets them know when to move on to new material. Thus, assessment has the capacity to enGauge.

Features of a Well-Designed Assessment Plan

Three key components comprise effective instruction: a clear description of learning goals; opportunities for students and instructors to determine progress toward and achievement of the goals; and strategies, skills, and experiences that help students achieve the goals. In a comprehensive review of research about assessment in the classroom, Black and Wiliam (1998) concluded that ongoing assessment plays a key role—*possibly the most important role*—in shaping classroom standards and increasing learning gains. They reported that well-designed, regular assessment of students had more impact on student learning than any other educational interventions. In addition, they found that high-caliber formative assessment increased learning gains for all students, but it had the most impact for low-achieving students. According to Black and Wiliam, ". . . formative assessment . . . is at the heart of effective teaching." Thus, assessment—the process of determining progress toward and achievement of

> ". . .ongoing assessment plays a key role —*possibly the most important role*— in shaping classroom standards and increasing learning gains."

goals—is an essential component of quality instruction.

The primary feature of assessment is that it provides feedback to instructors and students about learning and teaching. But to be *effective* assessment, the feedback must guide changes in instruction, curriculum, and learning behaviors. Black and Wiliam argue that effective assessment informs instructors how students are progressing toward learning goals *while the learning is going on*. The feedback from assessment guides midcourse changes that can help move students toward the learning goals. Moreover, a well-designed assessment plan motivates students to take responsibility for their own learning, helps them to gauge their own progress, and guides them to change behaviors in order to learn. To do this, effective assessment must align with learning goals and communicate clear standards of "excellent" performance.

In scientific teaching, the goal of assessment is to enGauge students in learning.

1. *Students* gauge their own progress toward the learning goals *during the learning process*. The feedback guides changes in learning behaviors and motivates a diversity of students to engage in learning.

2. *Instructors* gauge the students' progress toward the learning—and their own teaching goals—*during the learning process*. The feedback guides changes in instruction.

Key Features of Effective Assessment

Assessment engages students in learning.

When assessment is intentionally integrated into the curriculum as part of the routine, it constitutes a mechanism to engage students and shape their learning behaviors (National Institute for Science Education 1999). Specifically, well-designed assessment allows students to gauge their own progress toward the learning goals. Feedback from the assessment activities becomes an integral part of the learning process—instead of just a checkpoint at the end of a unit or semester. The feedback from a variety of assessments motivates a diversity of students to take responsibility for their own learning and guide them to change behaviors to achieve the learning goals. The effect is to catapult learning far beyond facts and figures, and to create an inclusive classroom where students come to understand the complexities of science.

A powerful way to cultivate an assessment-rich classroom is to design simple "enGaugements," which are active learning exercises that assess student understanding. EnGaugements are simple assessment tools that are designed to help students enGauge in learning. They can easily be integrated into a traditional lecture course of any size. Table 3.2 includes examples of enGaugements for college biology courses. For other ideas, refer to Angelo and Cross's book, *Classroom Assessment Techniques* (1993) or the National Institute for Science Education's Website on classroom assessment at http://www.flaguide.org (1999).

Assessment gauges learning—it provides feedback to students and instructors.

It's important for the instructor to cultivate an environment where all students have ample opportunity to gauge their progress toward the learning goals *during the learning process* (National Institute for Science Education 1999). When assessment is integrated into the learning process, students develop a clear sense of what they understand and what they need to learn, which motivates them to take responsibility for their own learning. This creates a classroom climate that is respectful and welcoming, yet clearly focused on learning.

What type of feedback can assessments provide? Both formative and summative assessments offer information about student learning that can shape learning behaviors and guide instructional decisions. Any assessment has two parts: the part the students *do*, and the part that defines the *caliber of performance*. For a multiple-choice question with a single, correct answer, this is simple: A correct answer indicates excellent performance. However, more complex projects that involve writing or presentation can be trickier to assess. In this case, it helps to have a mechanism for defining excellence. Rubrics can be powerful tools to help students achieve excellence, and to keep instructors focused on their goals. They can range from simple statements about the performance instructors expect to complex matrices that describe levels of achievement for myriad criteria. In addition, rubrics give students the freedom to make choices about the caliber of work they wish to do based on their own time constraints and learning goals. In fact, students can be part of the rubric's design. These tools are one more way to entice students to shoulder the responsibility for learning. For more information about rubrics, refer to

Huba and Freed's comprehensive book, *Learner-Centered Assessment on College Campuses* (2000).

Example: Using feedback about student learning to guide instructional decisions. Use a simple enGaugement to elicit students' prior knowledge about a topic, such as a brainstorm activity or a series of questions that students answer with an audience response system ("clickers"). If the results indicate that most students already know about the topic, the instructor may elect to skip the topic, probe deeper to determine how much they know, conduct a brief review, or delve into an application of that topic that requires more complex analytical skills. If the material was new to the students, or they had misconceptions about it at the beginning of class, the instructor might consider revisiting the same question(s) again at the middle or end of class to see if their understanding improved. If understanding does not improve, the instructor should consider why and decide what teaching action to take.

In addition to scientific questions, instructors might consider gathering qualitative data about teaching by asking students what they feel is most effective, what they like/dislike, whether they feel the learning objectives are being met, if they like working in groups, what they struggle to understand, or how the instructor might improve teaching and learning. Feedback from these types of questions can help quantify some of the more intangible aspects of teaching, and serve as a mechanism to improve instruction.

Assessment aligns with the learning goals and activities.

Alignment is the key to reducing curriculum clutter. It should be clear how achievement of the learning goals will be measured, what outcomes (skills, knowledge, behaviors) are expected, and which assessments will be used for grading purposes. Close alignment of assessment and learning goals helps simplify decisions about what to include and what to jettison. If a topic, skill, or behavior is important enough to represent a learning goal, then students progress toward and achievement of the goal should be assessed. Assessment reinforces the goal's importance and provides students with a framework for gauging their progress toward it.

Table 3.1. Example of assessment that aligns with learning goals.

Learning Goals	Evidence of student learning (expected outcome)	EnGaugement
At the end of this lab, students will understand 1. that bacteria are microscopic, unicellular organisms 2. that bacteria are ubiquitous but not necessarily culturable in lab conditions	Students will be able to explain what happens during the formation of a colony that appears on an agar medium. Students will be able to explain why, based on the colonies that appear on the agar medium, they can arrive at only an incomplete estimate of bacterial populations in natural environments.	Predict-observe-explain: Students are given three Petri plates with an agar medium and are asked to test the hypothesis that microbes are everywhere. PREDICT: *Touch an agar medium with your fingers and predict what you'll see in a week.* *OBSERVE: A week later, observe & record any changes.* *EXPLAIN: Did the observations match the predictions? Explain why the observations do or do not support the hypothesis. Are all of the bacteria on your fingers represented on the agar medium?*

In Table 3.1, the activity that students perform assesses their knowledge at three key points: at the beginning of the lab (students have to recognize what they *don't* understand about bacterial cells and growth when they make a prediction), during the lab (students have to decide what to measure and record), and at the end of the lab (students have to explain what a colony is in order to explain whether their evidence supports the hypothesis or not). In addition, this assessment can be used to test several other learning goals, such as the ability to design a controlled experiment with replicates, to understand the concept of microbial biodiversity, or to work collaboratively in groups.

Finally, it is important that the assessment plan does not become an onerous chore for the instructor or the students. Check the plan for redundancies. Is the same learning goal assessed more than once? Might that be helpful to different students, or is it simply redundant? Find creative ways to assess multiple learning objectives with a single activity or to have students assess their own progress based on the criteria provided.

A Word about Grading

The reality of most courses is that, at the end of the semester, instructors need to assign a grade. This is where *assessment* becomes *evaluation*. While formative assessments provide the instructor with ongoing feedback about student understanding, a second type of assessment—"summative" assessment—measures progress at defined points in the semester. A well-designed assessment plan should lend itself readily to grading. Students should have a clear vision of what the instructor expects in terms of knowledge, skills, and performance, and they should have already assessed their own learning (and their peers') at many points during the course. Summative assessment helps gauge how well the students have learned the material and supplies data that can be converted into a grade. The important point to remember is that assessment is *more* than grading; it offers ongoing feedback to students and teachers alike. Examples of summative assessments include comprehensive exams, final oral presentations, or poster symposia. Rubrics can be very helpful in grading; a well-designed rubric should make grading more objective and straightforward.

Table 3.2 Examples of EnGaugements for Biology

The goal of enGaugements is to provide feedback about learning to both instructors and students. While instructors may choose to grade these assessments, they are also helpful to give context to the topic they are lecturing about, motivate students to participate in and take responsibility for their own learning, and offer them the opportunity to think critically. Many of the activities work best when students work together in pairs or groups of 3-5, but some work best as individual activities. In addition, the enGaugements can help instructors determine what works best for their own teaching style.

Brainstorm

Brainstorming is possibly the fastest and easiest way to incorporate active learning into a large lecture, and it is a quick way for students to assess what they already do or don't know.

Example: *What does a plant need to survive?*
This activity works well for any organism, and drives home the point that students already know more than they think they do. The list can go on and on, if students start to list individual minerals and other components. But no matter what they come up with for the brainstorm list, it can always be separated into two categories. For example: abiotic vs. biotic factors or environmental vs. genetic requirements. These categories can then be used as the basis for a subsequent lecture or laboratory exercise.

Pre/post test

Pre/post test is another simple way to help students gauge what they've learned. If their answers don't change over time, it tells the instructor that something is amiss with the learning, the teaching, or the assessment.

Example: *Describe two ways a bacterium could harm a plant.*
Have students write down their answers during lecture, then finish the class and have them answer again (post-test). Have students compare their two answers.

Think-pair-share

Think-pair-share activities work well to encourage group learning. Students answer a question individually, then share their answers with other students nearby and discuss which answers make the most sense. After 3-5 minutes, some of the groups report their conclusions. An optional step can be added to include experimental results. It's helpful to compare student answers from before and after discussion. This activity works well with electronic audience response systems or "clickers."

Example: *Experimental design consists of three treatments of radish seed sets:*
- *(1) light, no water*
- *(2) light, water*
- *(3) no light, water*

Which set of plants will have the lowest dry weight after 3 days?

First, students answer the question individually for 1-2 minutes. Next, they work as groups to share and discuss their answers and come to consensus. After 3-5 minutes of discussion, the students answer the question again. Finally, show the actual experimental results: *Treatment #3 has lowest biomass.* It's important that students discuss the experimental results with their group so they can figure out themselves that the result only makes sense if they understand that respiration, in addition to photosynthesis, occurs in plant cells. *This example is used with permission from (Ebert-May et al. 2003)*

One-minute paper

One-minute papers are a great way to capture what students are thinking. For example, when used at the end of class, the instructor can gauge what students have learned by asking them to list the three most important things they learned that day in class. At the beginning of class, the instructor can gauge what students retained from the previous lecture or a reading assignment.

Example: At the end of a lecture about the structure of DNA, give this assignment to read about the structure of DNA through an online resource (www.dnai.org/a/index.html) or a textbook chapter. Students are expected to write a one-minute paper at the beginning of the next class period about DNA replication: *What about the structure of DNA suggests a mechanism for replication?*

Predict-observe-explain

A predict-observe-explain activity is a simplified version of the scientific method, in which students make predictions based on a hypothesis, observe results, and explain how the predictions and observations relate to each other. In this activity, students need to identify what they don't understand about bacterial growth.

Example: Microbes are everywhere. *Touch an agar medium with your fingers and predict what you'll see in a week. A week later, observe what grew on the medium, describe whether the observations support the hypothesis and match the predictions, and explain why.* Alternatively, the instructor provides data for an experiment that students explain.

Concept map

Concept maps can be a powerful tool for students to assess their own learning because they need to create a visual representation and verbal explanation for complex concepts.

Example: *Explain how these terms relate to each other by arranging them in a logical order:*
Protein, tRNA, DNA, transcription, amino acid, translation, replication, gene expression, promoter, nucleotide.

What's wrong with this statement?

One of the most powerful learning tools is to have students explain why a statement is incorrect.
"I don't want to be eating any viruses or bacteria in my food, so I won't eat genetically modified plants."

Case

Cases offer the opportunity for rich exploration into many concepts in the context of a real-world scenario.

Example: *A patient had itchy, goopy eyes, so he went to the doctor. The doctor diagnosed the irritation as conjunctivitis and prescribed antibiotics. Symptoms cleared up within a few days. The infection reoccurred two weeks later. The patient called the doctor, and she advised taking antibiotics again. The patient washed his sheets in hot water, washed his hands incessantly, cleaned his keyboard with soap and water, and bleached the washcloths he used to wash his face. The infection reoccurred again two weeks later. The patient called the doctor, who advised taking antibiotics again.*

(1) *Write three hypotheses to explain why the infection reoccurred.*
(2) *What should the patient do? Should he take the doctor's advice? Describe any assumptions you make and justify your recommendation with biological reasons and principles.*

Rubrics

What is a rubric?

- Webster: "an authoritative rule…an explanation or introductory commentary."
- Dictionary.com: "An authoritative rule or direction; a short commentary or explanation covering a broad subject."
- Huba & Freed, 2000: "Rubrics explain the scoring 'rules': the criteria against which student work will be judged. More importantly…it makes public key criteria that students can use in developing, revising, and judging their own work."

Why should I use a rubric?

1. Rubrics are perhaps the most powerful assessment tool for fostering student responsibility for learning because they make explicitly clear what performance and progress is expected. Students can use the rubric as a guide to evaluate their own progress and as a tool for reviewing each others' work.

2. Rubrics can educate students about the standards we expect in science and research. Clear articulation of scientific norms teaches students about common practices and the language we use to convey ideas.

3. Rubrics can help you assess progress toward your own teaching goals. By quantifying student progress toward the learning goals, you generate data that you can use to guide future instructional decisions and to serve as evidence of the caliber of your teaching. In addition, rubrics make transparent your intentions to colleagues, which can open lines of communication and foster discussions about teaching-related issues.

What criteria belong in a rubric?

It depends on your purposes. If the rubric is being used as a tool for evaluating student achievement of the goals for the entire course or a big project, it might focus more on global objectives. For example, the rubric might describe the extent of accuracy and clarity expected for all projects in the course, regardless of what the content is. On the other hand, if the rubric is designed to measure progress toward understanding specific content goals, it might focus on clear descriptions of what students should know, understand, and be able to do that are related specifically to that material.

Regardless of the scope, a rubric should always provide a means to measure progress toward and achievement of the learning goals. Including ancillary criteria in a rubric—criteria that are not included in the course's learning goals—is confusing and frustrating for students. Remember that *assessment drives student learning*; if you want students to focus on accomplishing the learning goals, then let the rubric guide their actions in that direction.

What type of language should be used in a rubric?

Terms should be descriptive, explaining clearly the characteristics or qualities you expect to see for each level of performance. Similarly, descriptions should be qualitative, not laden with value judgments or comparisons. Many rubrics also include a statement about the consequences of each performance level.

Myriad terms define the highest caliber of performance, including "comprehensive," "complete," "sophisticated," "exemplary," or "excellent." Regardless of which you choose to use, each term warrants a complete description of its unique qualities. Intermediate or lesser performances deserve the same attention; simply reducing the quantity of incidents is not effective or informative. Rather, provide clear descriptions that describe the qualities and consequences that characterize typical performances at that level.

The example below is based on an activity in which students write a report to propose a new genetic engineering technology to the FDA. Notice how the second rubric includes qualitative descriptions for each criterion and brief statements about the consequences for each level of performance. The second rubric is adapted from Huba & Freed (2000).

Instead of:

Criteria	Excellent	Good	Poor	Unacceptable
Accuracy of information	No errors were made.	1-3 errors were made.	4-6 errors were made.	More than 6 errors were made.

Try:

Criteria	Level of performance			
	Sophisticated	Good	Needs improvement	Unacceptable
Accuracy of information	No factual errors were made. Your work will be very useful in aiding the reader to make a decision about whether this genetic engineering technology would make a significant contribution as an alternative method to pesticide use in agriculture.	No significant errors were made. The reader recognizes any errors as the result of hasty conclusions or oversights. Your work is usable for making decisions about employing this technology but would be considered more reliable if you were more careful in proofreading your work.	Enough errors were made to distract the reader, but the reader is able to use the information to make judgments. The technology will appear more useful if the reader is able to decide what evidence is reliable.	Your proposed technology is highly improbable because there are so many factual errors. The reader cannot depend on this report as a source of accurate information, or you have included so little information that the reader is not sure what the technology is all about. It will not be approved by the FDA.

Rubric Template

Your name: ______________________________

Course: ______________________________

Topic: ______________________________

Instructions: Write the criteria in the left-hand column and the levels of achievement in the top row. Complete the rubric with statements that accurately describe the qualities of performance at each level. Optional: include statements that indicate the consequences of each performance level.

Criteria	Levels of Achievement		

Chapter 4

Diversity

Chapter 4
Diversity

Diversity Defined

Human diversity refers to the variation of human experience, ability, and characteristics. Diversity should be considered in teaching because (1) we owe all of our students education about the diverse world they live in, and (2) diverse students will experience the same classroom differently. Their education, experience, cognitive styles, personalities, abilities, and innate characteristics will conspire to make the classroom experience unique to each student. Incorporating human diversity in science education and recognizing student differences and our reactions to them can prepare students more effectively for the global community and enable us to reach more students. In this chapter, we discuss ways to make our classrooms and teaching more inclusive to the diversity of human beings and more representative of the human experience.

Need for Diversity

A scientific community derives its health and vigor from diversity. Good science necessitates building teams that contain members with different approaches, experience, and ways of thinking. Evidence from controlled research studies shows that heterogeneous groups are more creative in problem solving than homogenous groups (Cox 1993, McLeod et al. 1996). Groups with a minority view defend their solutions to problems more effectively than those that do not contain a minority view (Nemeth 1985, Nemeth 1995). In studies of mock juries, those that contained members of ethnic minority groups deliberated more effectively and processed information more carefully than juries that lacked ethnic diversity. Studies of real life reinforce the results from controlled studies. A study of the teams that produced hit Broadway plays and high-impact scientific papers found that diversity of experience was a common feature of the most effective groups—the mixture of novices and veterans produced the most creative and successful teams (Guimerá et al. 2005). In short, fostering diversity is good for the creative process of science.

Diversity also enhances education. Studies of students in many different colleges and universities showed that a diverse student body produces better educated graduates who have more highly developed cognitive abilities, interpersonal skills, and leadership abilities (Astin 1993, Gurin 1999, Gurin 2002). Our students need to be effective in a global community in which they will confront a diverse workforce and deal with a range of human experience. Their education should prepare them for their future by offering them opportunities to learn about a world and people beyond their own experience and to work effectively with people whose backgrounds differ from their own. Therefore, our students—and science itself—benefit from building a diverse scientific community and presenting science in a global context.

The scientific engine of the United States is not taking full advantage of the diversity or brainpower that it trains. In many fields, such as biology and chemistry, nearly 50% of the Ph.D.s have been granted to women for years, but the proportion of women in the faculty does not reflect this. Since women are well-represented among the very best graduate students, by not utilizing these talented women in academic science, the professoriate is not drawing on some of the best talent available.

Undergraduate educators can contribute to the diversity of the scientific community in various ways. By creating a classroom culture in which people of diverse cognitive styles, social styles, experience, race, ethnicity, and gender thrive and feel included, college educators can enhance the intellectual vigor of their classrooms and contribute to building a pool of confident, ambitious graduate students. The confidence and sense of belonging that these students acquire as undergraduates will buoy them through difficult times when they feel disenfranchised by the scientific community because they display characteristics that mark them as different.

In sum, science and education will be strengthened by attracting diverse intellects and personalities to our classrooms and providing environments in which diverse people succeed flourish. In the following sections, we explore different elements of diversity and strategies to accommodate and nourish them in the university science classroom.

Diversity in Cognitive Style

Most manifestations of diversity are invisible and unknown even to the person who harbors them, but these elements of diversity can have profound effects on learning. Childhood experiences, education, relationships, and personality all contribute to the development of the mind, making thinking one of the most idiosyncratic of human activities. In a single classroom, there may well be students whose thinking is dominated either by intuition, logical deduction, or inductive reasoning. Some people favor learning details and deriving a global view from the facts and pieces. Others may learn best by starting with a principle and supporting it with examples. Some are driven by curiosity, others by emotion; some are visual learners, others are aural, and still others are kinesthetic learners, who learn best by doing. Some learn best in a competitive context; some are paralyzed by competition.

No teacher can know the cognitive styles and learning preferences of every student. Therefore, the only feasible strategy to reach diverse intellects is to use diverse teaching techniques and offer choices in the types of resources offered to students. A mixture of formats—lectures, labs, and discussions—and intellectual constructs—fact memorization, derivation and application of theory, and discovery—will reach more students than a monochromatic classroom centered on one technique and style.

Diversity in Race and Gender

Variations in cognitive styles among students may be hard to detect, but other differences among people are easy to see. Race and gender are among the first attributes we notice about people. Moreover, most people identify much more strongly with the group defined by their gender or race than the group defined by their cognitive style, and society makes much sharper judgments based on race and gender, the impact of race and gender on the classroom is evident and important, so it is worth spending some time thinking about the research in this area. Conscious thought about race and gender in the classroom can inform teaching methods and help avoid inadvertent discriminatory behaviors. We also have a responsibility to expose students to human experiences beyond their own. Therefore, choosing examples of biology that are drawn from diverse settings or involve diverse people is important in broadening the learning experience in our classrooms.

Can girls do math and science?

Much has been made in the popular press about genetic differences in aptitude for science between men and women. Careful analysis of the research on this issue reveals that although the field is highly controversial and much is made of data on both sides of the argument, there is little support for the assertion that men are more able to do math and science. The assertions about the boys' superiority in math, in particular, are made sufficiently often that it is worth examining the research. One highly publicized result is that math SAT scores have consistently been slightly higher for boys than girls for years (Spelke). However, many other lines of evidence indicate that boys and girls perform similarly in math. Boys' math performance is either slightly better or the same as girls' in early childhood (Hyde et al., 1990) and by high school, the gap has closed and girls do as well and in some studies appear to do *better* than boys (National Center 2004; Hyde 1990; Hyde, 2005). A recent study indicated that even the highly publicized difference in SAT scores may be more influenced by socioeconomic class than by sex ( ), which might be explained by the observation that boys in economically advantaged families are more likely to play with toys that build spatial skills, which contribute to success in certain types of math problems ( ). This last result underscores the point that even if there are measurable differences in performance – which seems questionable based on the available data – math aptitude is influenced by engagement in certain activities, and spatial skills are learned, not entirely innate. The role of learning and culture in math ability is also highlighted by the large differences in math ability among children in different countries. Girls in Taiwan and Japan, for example, perform far better than boys in the United States (Lummis and Stevenson).

By the time they reach college, there is no detectable difference in math performance of men and women. A recent study showed that women college students take as many math courses and perform better in them than their male counterparts (Evans et al., 2002). These results show that the SAT scores, which are poor predictors of college performance generally, certainly underpredict women's math performance in college.

Other cognitive differences between men and women have been studied as well. Girls consistently outperform boys in tests for reading and writing ability (Weiss et al, 2003; National Center 2003) and this gap appears in international studies as well as those conducted in the United States ( ) and over a large number of studies spanning two decades (Hyde and Linn, 1988; National Center for Ed Stats, 2000).

The aggregate of this research indicates that by the time students reach the college classroom, on average men and women are likely to perform similarly in math and women are likely to perform somewhat better in endeavors involving verbal skills. So what does this mean for science? Very little. We don't know much about the combination of skills that are needed to be an effective scientist. Most of us would probably guess that global intelligence, math skills, verbal skills, social skills, and hard work are all needed to be successful in scientific research. But how much of each is required? That's the impossible question. It is impossible to answer partly because these characteristics are impossible to measure accurately, they change over a lifetime due to experience and learning, and so many different types of scientists are successful. This last point is probably the most important – diverse scientific styles are successful, diversity keeps science vibrant and dynamic, and so there is no recipe of features of a great scientist.

So what does the research on gender and ability tell us about whether men or women are likely to become great scientists? Nothing. There are few measurable differences between men's and women's intellectual abilities, we don't know which abilities are important for doing science, and we need many different types of scientists with different abilities and styles. And finally, how does knowing anything about group traits help us as teachers? In our classroom role, we should treat our students as individuals and not judge their abilities or potential based on a group characteristic, real or imagined. But we will discuss later in this chapter, dismissing our unconscious biases about race and gender is harder than most of us think.

Diversity, learning styles, and pedagogy
People of certain races, ethnicity, or gender may have social or intellectual preferences that shape our choice of teaching methods. For example, some research shows that Native Americans learn better, on average, in a cooperative group than in a competitive system that spotlights the achievements of one student (Swisher 1990). Connections of course material to applications to enhance people's lives enhance many students' learning, but have a more pronounced effect on women (Rosser 1990). MORE RESEARCH HERE
These studies present generalizations that do not apply to all members of any group, but illustrate that some of our students may have learning styles that differ from each others' or from their instructors'. Teaching strategies and tools need to accommodate a range of styles, preferences, and experiences.

Diversity and Unconscious Bias

Although most people consider themselves fair, objective, and unprejudiced, *everyone* brings bias and prejudice to interactions with other people. Copious research, which includes both controlled experiments and analyses of real life situations, shows that we all apply assumptions and biases to our judgments of people and their work. For example, if subjects are asked to judge a set of credentials, they rated the quality of the materials lower if told the credentials were for a woman than for a man (Olian et al. 1988, Steinpreis et al. 1999). When asked to rate a subject's verbal ability based on a paragraph of text, evaluators gave a lower rating if they were told the paragraph was written by an African American person or a woman than if they thought it was written by a white person or a man (Biernat and Manis 1994). One research group sent a resumé of a real person to a large group of academic psychologists and asked them whether they would hire the person. The frequency of positive answers was substantially higher if the resumé had a man's name than if it had a woman's name (Steinpreis et al. 1999). In another study, evaluators were given a description of a person's career path and photograph of the subject and asked to judge whether the person's success was due primarily to ability, luck, or political skills. If the subject of evaluation was attractive, the attribution was quite different than if the subject was unattractive, but the trend was gender specific: more raters attributed success to ability for attractive than for unattractive men, but the response was reversed for women subjects, whose success was twice as likely to be attributed to ability if they were *unattractive*. (Table 4.1).

Table 4.1. Effect of attractiveness on perceptions of ability in men and women (Heilman and Stopeck 1985).

Subject of evaluation	Proportion of raters who attributed success primarily to ability
Unattractive male	34%
Attractive male	50%
Unattractive female	62%
Attractive female	28%

Similar observations are made in studies of real life evaluations. For example, a study of evaluation of postdoctoral fellowship applications in Sweden indicated that for male applicants, "impact scores" based on the number and impact of applicants' publications were tightly correlated with "competence scores," which were used to rank the applicants and award fellowships. For women applicants, however, impact scores were much less well correlated with competence ratings (Figure 1) and women needed to have many more publications (the equivalent of 3 more papers in *Science* or *Nature* and 20 more papers in a specialty journal such as *Neuroscience*) in order to achieve the same "competence rating" as their male counterparts (Wenneras and Wold 1997).

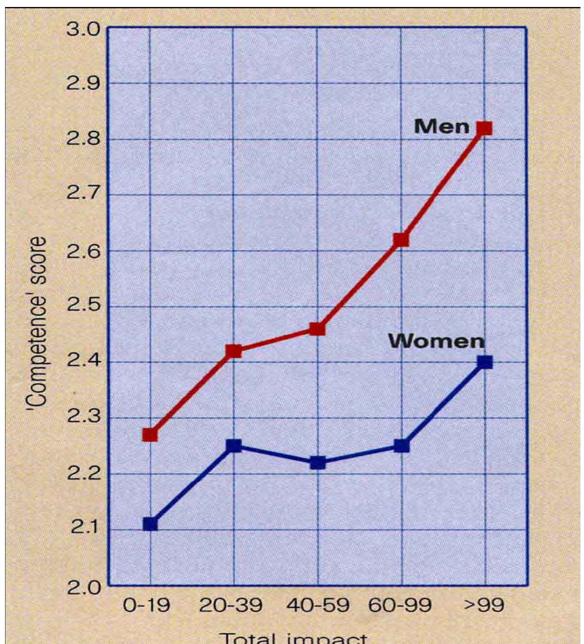

Figure 1. add legend

In the music world, symphony orchestras experienced a 60% increase in selection of women following the installation of screens that obscured the gender of people auditioning from the evaluators (Goldin and Rouse 2000)
These research studies illustrate the power of our unconscious biases. Our rational evaluations of quality are shrouded in a fog of cultural expectations of people with certain characteristics. A

key element of all of these studies is that in none of them does the gender of the evaluator show a significant effect on the results. This means that all of us are likely to bring similar unconscious biases to the classroom, even if we are the subject of those very same negative biases.

A teacher's challenge is to treat students as individuals, without expectations shaped by assumptions based on a group affiliation. Even more challenging is to maintain high expectations for and confidence in every student, even those who have performed poorly. Assuming that a student isn't fit for science based on one low exam grade may be as damaging and unfair as assuming that the student isn't fit for science because she is a woman.

How might unconscious biases affect our interactions with our students?
It is easy to imagine how our expectations of students might be shaped by unconscious bias. When we interact with a female student, do we assume that she is less competent in science than a male student? When we grade an African American student's paper, are we harsher on the writing because of an unconscious expectation of lesser writing skills? Students live up or down to expectations, so we do them a great disservice by expecting less than top ability and performance from every student.

What Can We Do to Enhance Diversity in Our Classrooms?

- **To reduce the impact of unconscious bias,** we can act as our own monitors. Being aware of the potential for bias is the most effective guard against it. We should regularly ask ourselves whether our treatment of our students is based on their behavior and performance or on expectations that have nothing to do with them. When a student we don't know approaches us with a question, is the level or depth of our answer shaped by their sex, race, age, or manner of dress? Do the thought experiment: If a student clanks toward me in black leather and chains, with a shaven head and pieced body parts, would I answer his questions differently than if he dressed the way I dress?

- **To enhance all students' exposure to the diversity of human experience,** we can use diverse examples in biology. Images of diverse natural habitats, races of people, and types of human activities can enhance the learning experience. In a section on the impact of human activity on biodiversity, we might include examples from other parts of the world or examples in which human issues that our students do not normally confront interface with ecological issues (the effect of poverty in developing countries on decisions about protection of the rain forest, for example). When we discuss human disease, we can include diseases that affect people across the globe, introducing our students to experiences beyond their own. When we show images of people, we should include images of men, women, and people of all races.

- **To make our classrooms inclusive and inspiring for women and people of color,** we can discuss the contributions—and show images—of diverse scientists. One study showed that people evaluated African Americans more favorably for about a day after seeing images of great African Americans, such as Martin Luther King, Jr., than if they were shown no images or negative images of African Americans (Blair et al. 2001, Dasgupta and Greenwald 2001). Extrapolating from these results, we can perhaps reduce bias toward women and minorities by providing our students with more examples of successful women and minority scientists.

- **To reduce the effect of personal bias in grading,** decide on criteria before starting to grade. One study showed that people construct criteria after the fact to justify unconscious discrimination, and having clear criteria for evaluation reduced their bias (Uhlmann and Cohen 2005).

- **Teach students about bias and diversity** by conducting diversity exercises. Have them examine behaviors (who talks and how much, who does the work, whose ideas prevail) when they work in small groups and discuss what they observe. Consider assigning reading about diversity and discuss it. Even if this material is not directly relevant to your scientific content, it *is* relevant to your students' ability to learn in your class. You also owe your students from majority groups some exposure to diversity issues before they enter the workforce where they are guaranteed to confront them. Many resources are available to foster these discussions (http://cirtl.wceruw.org/diversityinstitute/resources/workshops/).

Some Final Musings on Diversity

The "prejudice paradox" and the nature of bigotry

The reader may note an inherent paradox in the preceding sections. The section presenting the studies that show and association between cognitive style or preference and race, ethnicity, and gender suggests that educators may want to consider this evidence in choosing teaching methods and content in order to optimize learning for diverse students. The next section presents the insidious power of unfounded, unconscious biases about women and minorities. Is there a "prejudice paradox"? Are we advocating using research that makes generalizations about groups to shape our teaching and simultaneously warning about making assumptions about people because of their group affiliation? Both bodies of work can be accommodated by a simple cautionary thought: people differ in many ways – some that we can see or measure, some that are unknown or unknowable, and some that are imaginary, but assumed. We should treat every student as an individual who has the potential to be outstanding in science, but we should also assume that there is tremendous diversity in ability, experience, cognitive style, social preferences, and myriad other characteristics among our students. Efforts to accommodate this diversity can be informed by the characteristics associated more often with women, Native American, or African American learners, but we should never assume that any individual has characteristics associated with a group. Afterall, that is the definition of bigotry.

Why are we resistant to believing that discrimination exists?

Many academic scientists think that we have solved discrimination problems. Many say that we judge people based on quality alone, that we treat all of our students the same, and that discrimination is a thing of the past ( ). A recent study at the University of Wisconsin showed that department chairs (mostly white men) rated the climate for women and minorities more positively than did women and minorities. When confronted with data that demonstrate discrimination, many people will quickly generate hypotheses about how the data might be flawed and therefore are not really evidence that discrimination is alive and well (Box 1 and 2).

Why are people resistant to the idea that humans are biased and discrimination is quite alive in our society? No one knows the answer, but there are some speculations. Most people would like to believe that they live in a fair world and these data challenge that belief. Many people see women and minorities in their universities and assume therefore that things are going well on the efforts to diversify the universities. Even more fundamental is the flip side of discrimination: if we accept that others suffer from discrimination, then those who do not suffer discrimination necessarily benefit from the privilege of being white or male. Few people want to believe that their own success was due in part to personal advantage. Scientists are particularly uncomfortable with this idea because they cling to the image of the scientist as a lone ranger, a pioneering cowboy striking out where no one has gone before, alone and with nothing but his ingenuity and ability to deal with adversity as his aids (Lawrence, 2006). Scientists may believe that their successes are diminished if they did not arise from hardship, deprivation, and a tough fight, but rather were assisted and protected by the privilege of being white and male and therefore part of a social group that has automatic credibility and is connected by a network of members of the same group.

> Box 1.
> The chancellor of the University of Wisconsin, John Wiley, remarked once that he never hears men generate rationalizations as fast as when he presents data indicating that women are suffering discrimination. His argument is that at some point between college and faculty positions, women in the physical sciences must be suffering from discrimination because in his university the women have higher grade point averages than men in every major, including electrical engineering, physics, chemistry, and statistics, where there are very few women faculty. He reports that whenever he cites the grade point data, men begin to fire off hypotheses, trying to escape the possibility that women are just as qualified for careers in the physical sciences.

Every educator is responsible for providing equal opportunity in education. No one can eliminate his or her own biases and prejudices, but each has an obligation to minimize their impact on treatment of students. It is natural to bring what we know about our students to bear on how we teach them – we teach first year students differently than seniors, majors differently from non-majors – but we need to confront our assumptions about individuals and give every student the chance to excel. It's the law, it's right, and it will strengthen the practice of science.

> Box 2.
> In a recent discussion of hiring practices at a large research university, the provost, a highly respected social scientist presented a summary of studies that illustrate that people have unconscious biases. She told her audience that she had carefully chosen studies that were scientifically sound and convincing. After her presentation, a number of men began to argue that the studies were wrong. They argued that one study was not relevant to their colleagues because it was conducted in Sweden, not the U.S., another argued that many of the controlled studies are conducted with undergraduate volunteers and they are not representative of university faculty, and another colleague (ironically, a statistician) announced that the studies weren't valid and launched into a story about how he tried to examine gender differences in his class and was misled by the data because he didn't control for certain variables. None of these people had read the studies, they had just heard them presented by a trusted colleague who was an expert in the field, and none asked questions, but instead pronounced the studies invalid.

In Conclusion

This latter section may irritate some readers. That's ok. This chapter is intended to lift the reader out of his or her comfort zone and induce consideration of emotionally and intellectually challenging issues. Teachers who grapple with the complexity of social science data about students and the messiness of race and gender issues in the classroom are better equipped to reach diverse students than those who avoid the issues. Each will arrive at different conclusions from evaluating the data and every teacher develops personal strategies for reaching many different kinds of students. And that's the power of having a diversity of educators in our university classrooms.

Chapter 5

A Framework for Constructing a Teaching Plan

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A Framework for Constructing a Teaching Plan

This section presents a scaffold (Table 5.1) that can be used to structure any class session or series of sessions for any type of course. Once this approach becomes habit, teaching plans are easy to construct. In addition to providing a structure, this section provides examples of active learning, assessment tools, and diversity strategies that can be incorporated into teaching plans.

Table 5.1. A framework for scientific teaching.

			Alignment
What do I want students to know, understand, and be able to do?	How will I determine whether students have met the learning goals? How will students assess their own learning?	What techniques will I use to engage a diverse group of students in active learning?	Are the activities and assessments aligned with the learning goals?

Backward Design

In developing a framework, it is useful to return to "backward design" (Chapter 1) (Wiggins and McTighe reference) and use it as the basis for a conceptual framework building effective teaching plans. In this section, we use a modified version of backward design:

1. **Identify the learning goals.** What will students will know, understand, and be able to do?
2. **Establish what criteria will be assessed.** How will students and instructors gauge progress toward the learning goals?
3. **Plan learning experiences and instruction.** What activities will engage a diversity of students in learning?
4. **Align and revise.** Do the activities and assessments engage students in achieving the learning goals and in gauging their progress toward the goals?

The following sections outline the steps in developing instructional materials according to the backward design paradigm.

Step 1: Set Learning Goals That Reflect the Nature of Science

The first step in developing a teaching plan is to establish learning goals that reflect the many facets of science. In 2003, the National Research Council published *Bio2010* (Council 2003), a report that offered recommendations for new biology curricula that better reflect the nature of science as a dynamic, interdisciplinary, and rapidly changing frontier. *Bio2010* echoes the 1989 call for a scientifically literate public by the American Association for the Advancement of Science in *Science for All Americans* (Rutherford 1990), which charged higher educators with teaching scientific habits of mind. In addition, large companies are demanding more efficient and effective employees with problem-solving capabilities, the ability to work in teams, and analytical skills.

These reports confirm that the traditional college curriculum, designed around information and factual knowledge, provides insufficient education for the new scientific workforce. They recommend that college courses retool their goals to highlight conceptual understanding, interdisciplinary context, authentic scientific experience, and interpersonal skills. Transforming classrooms to emulate the true human, dynamic enterprise of science is likely to increase the heterogeneity of students who are attracted to scientific fields of study, and it will augment all students' marketable skills. In short, practicing real science in the college classroom benefits everyone.

Building a framework with learning goals

With these reports in mind, determine what you want to accomplish in your classroom. As in any scientific experiment, having clear goals will provide organization, structure, and logic to the rest of your endeavor. Ask yourself the key question:

- **What do I want my students to know, understand, and be able to do?**

The answer to this question undoubtedly has many layers because specific goals are unique to each instructor, course, and group of students. For example, the detailed knowledge about specific molecules and chemical reactions that is needed to understand the Kreb's Cycle during a biochemistry unit may be different than what students need to know one month later during a unit on bacterial physiology. In one course, it may be essential for students to build skills working in groups, while group skills may be ancillary in the next course. Not every course needs to cover all goals of the college biology curriculum, and not every course will award each goal the same attention. What matters is that the learning goals make explicit what understanding is critical during a particular course or unit at a particular moment in time, that the goals represent the nature of science, and that the goals link to the broader aims of the entire undergraduate curriculum.

One key element of setting your learning goals is to focus on *learning*, not teaching. Consider what you want your students to learn, not what you want to teach. Many of us are in the habit of teaching what we want to talk or think about, instead of thinking of the minutes we spend in class as belonging to our students. It is their time to structure and initiate learning. More specifically, the goal is for students to *understand.* According to Wiggins and McTighe (1998):

> *Understanding involves sophisticated insights and abilities, reflected in varied performances and contexts. We also suggest that different kinds of understanding exist, that knowledge and skill do not automatically lead to understanding, that misunderstanding is a bigger problem than we realize, and that assessment of understanding therefore requires evidence that cannot be gained from traditional testing alone.*

Think of your class session as the time to stimulate interest and initiate learning, not as the complete package of knowledge your students will attain. How will you capture your students' interest in the subject and motivate them to learn on their own? What will you do to impart a structure and conceptual framework for them to use to organize information? How will you provide them an opportunity to construct their own knowledge?

Table 5.2 . Examples of learning goals that represent the nature of science*

Aspect of Science	Example Goals*
Knowledge	Know key concepts and seminal facts in the discipline. Understand which techniques are used to answer which scientific questions.
Skills	Be able to design and conduct scientific investigations. Be able to think critically about how experimental evidence answers a scientific question. Be able to perform relevant laboratory techniques.
Behaviors	Collaborate with other people. Communicate and defend a scientific argument. Implement a technological solution to solve a scientific or societal problem.
Attitudes	Be curious about the world around us and motivated to take responsibility for learning about it. Appreciate the relevance of scientific discovery in today's society and throughout history. Empathize with the hard work it takes to do scientific research.

**For more more learning goals that represent the nature of science, see the National Science Education Standards {National Research Council, 1996}, available freely online at http://www.nap.edu.*

Key things to consider when setting learning goals:

Elucidate the hierarchy of learning goals—Learning goals are paramount to differentiate what materials are essential, important, interesting, or irrelevant. The hierarchy of goals becomes the scaffolding on which the rest of the unit is built. Therefore, it is important to delineate what epitomizes lasting understanding and what is considered transient knowledge. As you review and revise goals, jettison superfluous materials and experiences that will not help students meet the learning goals. In short, ensure that learning experiences align with the learning goals. See figure 5.1.

The varying degrees of importance given to different learning goals should be made explicit to students. Students need to learn to recognize that topics carry different weight altogether from concepts, that they are used to illustrate the concepts, and that certain concepts are more integral than others. See Table 5.3 for examples.

Fig. 5.1. **Filter for learning goals.** When developing instructional materials, first categorize which goals are essential, important, or interesting. Jettison the superfluous materials.

Primary conceptual goal
These are essential to understand.

↓

Secondary conceptual goals
These are important to understand.

↓

Specific topics
These illustrate what is to be understood or are interestig to be familiar with.

↓

Superfluous materials
These materials should not be included in the lesson.

Table 5.3. Examples of specific learning goals that represent two aspects of the nature of science

Examples of learning goals**	
	Primary conceptual goals *These tend to be general, global, or lasting.*
Content	Students will understand that populations of organisms evolve because of variation and natural selection.
Skill	Students will be able to design and conduct scientific investigations.
	Secondary conceptual goals *These typically are more specific and may be ephemeral.*
Content	Students will know that a mutation in DNA can lead to a change in protein structure and function.
Skill	Students will be able to analyze experimental data and explain clearly whether the results support the hypothesis.
	Specific topics *These generally illustrate the concepts with specific examples.*
Content	A mutation in the P53 gene at codon ___ in human DNA can lead to uncontrolled cell division, resulting in a tumor.
Skill	Students will be able to work together to design and conduct an experiment to determine the cause of leaf death in an apple orchard.

***Content goals were adapted from Khodor, et al. {2004}. This article is available freely online at http://www.cellbioed.org.*

A great resource about the hierarchy of goals for *biological content* is the online article by Khodor et al. (2004). The article and its companion website provide a hierarchy for concepts in introductory biologiy at their institution (Massachussetts Institute of Technology). The article can be used as a starting point for framing biological content goals for your course or as a model for establishing hierarchy among other learning goals.

Content matters—An important goal of any course is to ensure that students learn the scientific content that is appropriate and expected in that discipline. There is so much to teach in biology; no one could possibly teach it all. How does an instructor choose which content to include? Before you include new materials, carefully evaluate its role by asking:

- **What information is essential to achieve the learning goals?**

Content is important, so make sure it's accurate. This may sound obvious, but it is striking how often introductory texts and instructors provide inaccurate or outdated information, doing a disservice to the students, the instructor, the course, and to science. Science requires knowledge of memorized facts, figures, and principles. But facts are learned and remembered better when they are presented in a scientific context and when students have the opportunity to apply them. Thus, using concept-based learning that emphasizes application of knowledge does not mean abandoning the goal of learning facts, it means learning them better.

Consider what students already know and target the difficult concepts—As you consider what you want your students to know, understand, and be able to do at the end of the class, identify the potential roadblocks to their learning by asking:

- **What do my students already know that can be used as a foundation for learning?**
- **What are the conceptually challenging aspects of this material?**
- **What misconceptions will some students have?**

Identifying these teaching challenges will help to focus the rest of your planning. You can tailor your content and teaching methods to the challenge, investing your time and material where it will have the greatest learning outcomes. Educational journals are a great place to start; most common misconceptions in biology have been identified, often with solutions. The goal of identifying these challenges is to deal with them (either by accepting them or by resolving them) so that you can focus instructional design on what you want your students to know, understand, and be able to do.

Example of prior knowledge and a misconception

College students typically know that many plant cells can photosynthesize, but few realize that *all* plant cells respire.

See page XXX for an EnGaugement that addresses this misconception.

Step 2: Develop Evidence of Learning: Assessment

The next step in developing a teaching plan is to determine what qualifies as acceptable evidence that students are learning. This step translates learning goals into specific outcomes that students should achieve and involves creating ideas and strategies to optimize assessments and use them as a range of teaching methods, not just a means to assign grades.

Learning goals are a great way to ensure that the teaching plan provides opportunity for students to use many different types of thinking skills. Bloom's Taxonomy (Bloom 1994) has established a lexicon for translating the goals into outcomes—the actions that we expect students to take. Bloom's Taxonomy provides a simple hierarchy of difficulty, using verbs to distinguish the levels. Evidence of learning that requires students to "list" can be complemented by more complex tasks that require students to "generate," "interpret," or "justify." Table 5.3 presents examples of evidence that students are achieving the learning goals.

Table 5.3 Examples of evidence of student learning based on learning goals.

Learning goal	Evidence of Learning (outcome)
Students will know the structures of the amino acids.	Students will be able to draw each of the amino acids and group them based on chemical properties.
Students will understand the role of mutation in evolution.	Students will be able to explain the role of mutation in evolution.
Students will understand the relationship between genes and proteins.	Students will be able to complete a concept map using the following terms: DNA, RNA, protein, transcription, translation, replication, amino acid.
Students will have an appreciation for the complexity of socioeconomic, ecological, and biological issues that surround genetic engineering.	Students will be able to defend (or refute) the importance and risk of genetic engineering in a debate.
Students will understand how to design an experiment.	Students will be able to formulate a hypothesis about solute transport, design an experiment to test it, and interpret the results.
Students will understand the importance of invasive species in ecosystems.	Students will have worked together to solve a case and present an oral report about the spread of an invasive species.
Students will know the role of Barbara McClintock's work in our understanding of transposable elements.	All students will have the opportunity to pose a question to the entire class about the impact of McClintock's work on transposable elements.

The same outcomes can be assessed in many formats: in-class exercises, exams, or semester-long projects. Keep in mind that assessment drives student learning, so it is important to design questions and assessment activities that motivate students to learn, give them feedback about their learning, and guide changes in their learning behavior. Table 5.4 provides a structure for thinking about the role of assessment in learning.

Step 3: Plan Learning Experiences and Instruction

Now for the fun part! The next step in developing a teachable unit is to plan activities that will help students achieve the learning goals. Now is the time to gather all those creative activities and ideas together and decide which ones will help your students achieve the learning goals. This is a great time to talk with your colleagues about activities they've tried and to delve into the online digital libraries for ideas. Chapter 2 is loaded with ideas for activities.

The filter for learning goals (Step 1) becomes important again here; this time it applies to assessments and activities as well. For example, if an activity doesn't help students meet the learning goals in some way, or if a disproportionate amount of time will be spent on an activity for a minor goal or specific topic, it probably should be modified accordingly or not used at all. The same goes for assessment. A fact-based quiz at the beginning of class ought to be testing information the students need to know. A key question to ask is:

- **What material can students learn best in a lecture, discussion, or lab, and what could be learned just as well on their own or in groups?**

Most learning occurs *outside* the classroom, so classroom time should be carefully constructed to motivate students, frame the concepts, and identify challenges. Perhaps you can forgo showing the students the structures of all of the amino acids, which you will ask them to memorize outside of class anyway, and instead discuss the chemical properties of amino acids, and then ask the students to use the principles in solving problems about protein chemistry, to help them apply the structural information and understand why it is important.

Key things to consider when planning learning experiences

Instructional resources—Don't reinvent the wheel if you don't have to! Instructional materials abound on the Internet and in print. Try searching for course syllabi, active learning exercises, quizzes, exams, images, and other resources online. A great place to start is a "digital library" for instructional materials, such as:

- NSDL, the National Science Digital Library (http://nsdl.org)
- BEN, the BioSciEdNet (http://biosciednet.org)
- MERLOT, the Multimedia Educational Resource for Learning and Online Teaching (http://www.merlot.org)

These libraries contain vast amounts of freely available, peer-reviewed instructional material that can be used as is or adapted to meet the learning goals of your course. Search broadly, because you might find a great active learning exercise in chemistry or a case study in physics that could be adapted to teach neurobiology. In addition, you might try searching for ideas in an educational database such as ERIC, the Education Resources Information Center (http://www.eric.ed.gov), or with your professional society's educational section.

Additional examples of instructional materials that are designed to address scientific teaching themes can be found in the Appendix.

Address misconceptions head-on—Educational researchers have been studying student misconceptions in science for years. By searching educational databases, you may find exactly the misconceptions that your own students harbor plus strategies that have proven effective in addressing them. Design activities to address these misconceptions directly. Interestingly, it is far easier to teach a subject that people know nothing about than to correct misconceptions because telling the answer is rarely effective in replacing a misconception. If students believe that the foundation of evolution is willful adaptation of individual organisms in response to changing environmental conditions, lecturing them about Darwin's theory of natural selection likely won't change their minds. However, if students have the opportunity to grapple with results of Darwin's observations—in which natural selection and variation are the only logical explanations—they are more likely to recognize that their Lamarckian explanations are inconsistent with the new data that they are contending with. With this approach, they are reconstructing their own knowledge based on new information or new experience. This is the essence of learning.

- **What misconceptions and prior knowledge might students have?**
- **What are the conceptually challenging aspects of this material?**

Vary the content and examples (for the purposes of inclusivity and diversity)—Part of the thrill of teaching is to be able to share what we know about best, so we choose examples based on what we know. But sometimes the examples we choose can be exclusive to students in subtle ways we never considered. A single illustration may not be offensive to anyone, but over the course of a semester in many classrooms, female and minority students do not see people who look like them represented in images or examples. This can lead to a feeling of exclusion and alienation. The same is true for sports, military, or mechanical metaphors or analogies that may only make sense (or be interesting) to certain members of the class. Changing the examples doesn't take any more time in the classroom, and the benefit is to make more diverse students perceive themselves as part of the scientific community.

Test your materials—Don't underestimate your colleagues' usefulness. If you just can't envision how an active learning exercise will play out in class, try it on a colleague and get feedback. In addition to obtaining specific feedback, you may develop an important collegial friendship for teaching, much like the kinds of friendships many of us treasure in research. Better yet, try it on a group of undergrads.

Design classrooms for learning—Is it possible to reconfigure the classroom to foster group work and learning? Yes! For ideas about effective classroom design, refer to the SCALE-UP project in physics (http://www.ncsu.edu/per/scaleup.html) (Beichner et al. 1999). Is the classroom wired for technology? Does the institution have any resources for classroom design? If the classroom can't be changed, consider what group size will be most effective so that students can work regularly in groups for classroom activities.

Learn to manage classroom dynamics effectively—Doing active learning exercises, group work, and ongoing assessment creates a classroom dynamic that is unfamiliar to many of us. For ideas about how to manage the classroom effectively during these activities, see Chapter 3.

Step 4. Alignment

Early in this chapter, we described learning goals, assessment, and activities as the three key components of the framework for a Teachable Unit. (Table 1.1) Alignment, the last step in building this framework, propels the framework into a full-fledged Teachable Unit. The primary goal of this step is to determine if the goals, assessments, and activities are aligned with each other. In other words, alignment helps determine whether

1. the assessments are designed to drive student learning toward the goals and provide ample opportunity for students and instructors to gauge progress toward the goals
2. the activities in the unit are designed to help students meet the learning goals
3. the learning goals are appropriate

Alignment highlights the concept that designing instructional materials is an iterative process. Even though we describe this process as linear, it really is a cyclical process that requires reflection and revision at every stage in development. If the activities and assessments don't help students meet the learning goals, then they should be revised accordingly. Often, the learning goals become more refined during this process, too.

Table 5.5 Alignment of learning goals, assessment, and activities.

			Alignment
What do I want students to know, understand, and be able to do?	How will I determine whether students have met the learning goals? How will students assess their own learning?	What techniques will I use to engage a diverse group of students in active learning?	Are the activities and assessments aligned with the learning goals?

Format of the Teachable Unit

A **comprehensive teachable unit** (Fig. 5.2) provides the framework and detailed instructions needed to teach the unit. It is important that the unit includes information for both students *and* instructors. This format exemplifies scientific teaching because every step in the process is justified and aligned with the other steps. Table 5.6 provides descriptions of the features of a comprehensive teachable unit in detail.

Writing a unit in this format serves four important purposes. First, it provides the instructor with a framework for the unit to help keep on track and on time in class, and to make teaching choices that are based on priorities that have already been established. Second, it elucidates to students what they are supposed to be learning, how well they should understand it, and that the responsibility for learning is theirs. Third, and this is where scientific teaching is paramount, other instructors will better understand the reasons why a particular teaching method in the unit was chosen and how it is designed to help students meet a specific learning goal. Finally, this format provides an outline for publication or teaching reviews. By having clearly defined learning goals and assessment tools, instructors can easily collect data from student performance in the classroom to test the hypothesis that this unit includes valid teaching methods that are designed to foster learning.

In addition to a comprehensive unit, it can be helpful to share the framework of the unit. This **executive summary** (Fig. 5.3) should include a title; brief descriptions of the learning goals, assessments, and schedule of activities; and an overview of how the unit addresses the scientific themes of assessment, active learning, and diversity.

Fig. 5.2

Comprehensive Teachable Unit

1. **Detailed teaching plan**

    a. **Learning goals:** List what students are expected to know, understand, and be able to do at the end of the Teachable Unit, including content, skills, and attitudes.
    b. **Assessment:** Explain what assessment activities will help both students *and* instructors to gauge the students' progress toward achieving the learning goals, throughout the unit *and* at the end of the unit.
    c. **Activities:** Provide detailed schedules with a timeline of all activities for instructors *and* students.

2. **Instructions for implementation by other instructors**

    a. **Context:** Describe where the unit could be taught, including descriptions of the course, students, and institution
    b. **Tips:** Provide suggestions for instructors to guide students through the unit, including troubleshooting tips and guiding questions
    c. **Supporting materials**: Include essential materials for teaching the unit, including images, readings, website addresses, references, and black-line masters for copying

3. **Scientific teaching statement**

    a. **Student learning:** Describe how the unit is designed to foster student learning.
    b. **Alignment:** Explain how the assessment and activities of the unit are aligned with the unit's goals.
    c. **Justification:** Provide evidence that the unit addresses challenges that have been identified in teaching and learning this subject.
    d. **Scientific teaching:** Explain how the unit addresses the scientific teaching themes of assessment, diversity, and active learning.

Fig. 5.3

Executive Summary of a Teachable Unit

Title

Learning Goals: What students will know, understand, and be able to do

Assessment: How students and instructors will gauge student learning throughout the unit

Activities: What students and instructors will do to help students achieve the goals (schedule)

How does the Teachable Unit address scientific teaching with respect to the following themes?

Diversity

Active learning

Assessment

Table 5.6

Teachable Unit Review Rubric

Element	Levels of Completion		
	Comprehensive	**Intermediate**	**Cursory or Absent**
Learning Goals: Overall *What students will learn*	It is clear what students will know, understand, and be able to do after they have completed this unit. The goals represent the nature of science. The goals are challenging and appropriate for the intended students.	The goals are identified but could be stated more explicitly, or they could be more innovative or varied. The goals are clear, but they are too challenging, too simple, or do not address the nature of science.	The goals are vague, ambiguous, too broad or ambitious, too detailed or focused, lack essential information, or omitted. The goals do not represent the nature of science.
Learning Goals: Scientific Content *What scientific content students are expected to know*	It is clear what knowledge (concepts, topics, theories, facts, and terminology) students are expected to learn. It is clear why this content is interesting or relevant to students. The expected knowledge is accurate, challenging, and appropriate for the intended students.	Expected knowledge is identified but could be more specific, varied, or accurate. Expected knowledge is clear, but it is somewhat too challenging or simple. Some content is inaccurate.	Expected knowledge is vague, ambiguous, not specific, inappropriate, inaccurate, or omitted.
Assessment *How instructors will measure student learning* *How students will self-assess learning*	The assessments provide instructors *and* students with feedback about student learning. Assessments are designed to measure student progress toward the learning goals throughout the unit and at the end of the unit. Assessments are designed to drive student learning toward the goals. Criteria for evaluation and grading are clear.	The assessments provide some feedback to the instructors and the students but could be improved. The assessments align somewhat with the learning goals. The assessments include formative and summative formats but could be improved.	The assessments are incomplete or ambiguous. The assessments are not aligned with the learning goals. Feedback to students or instructors is missing. Formative or summative assessments are missing.
Active Learning *How students will engage actively in learning*	The activities are designed to help students meet the learning goals. Active learning and student-centered exercises are used effectively. The activities are interesting and engaging.	The activities could be better aligned with learning goals. Activities could be more effective or student-centered.	Activities are exclusively teacher-centered. Activities are ineffective, uninteresting, or omitted.

Teachable Unit Review Rubric

Element of the unit	Levels of Completion		
	Comprehensive	**Intermediate**	**Cursory or Absent**
Diversity *How a diversity of students will be reached*	It is clear that the unit is designed to allow students to construct their own learning in the context of their own minds, to foster student responsibility for learning, and to engage a diversity of students. It is clear that the unit addresses multiple aspects of student diversity, such as cognitive, racial/ethnic/cultural, gender, and ability. A diversity of teaching methods, content, examples, or metaphors are used, which are not offensive.	The unit offers some opportunity for students to construct their own learning, but could include more diverse or effective teaching methods. The unit could use more examples that reflect student diversity in cultural background, gender, learning skills, or physical abilities. The unit includes diverse teaching methods, but otherwise does not address diversity in students.	The unit is teacher-centered and does not foster student responsibility for learning. The unit does not address diversity or includes potentially off-putting examples.
Teaching Plan *What the instructor and students will do*	The plan includes a clear schedule of events for activities and assessments for both the instructor and the students. The sequence of events is logical and aligned with goals. Detailed instructions are provided so that another instructor could easily implement the unit, including guiding questions, tips, and supporting materials. Detailed instructions are provided for students.	The schedule of activities is described broadly, but more detailed instructions are needed for another instructor to implement. The order of events is somewhat logical, but could be improved.	The schedule of activities is vague, not logical, or omitted. Detailed instructions are not included for instructors or students.
Scientific Teaching *How the unit aligns with teaching and learning goals*	It is clear how the unit's activities and assessments are aligned with the goals. It is clear how the unit addresses the themes of diversity, assessment, and active learning. It is clear how the unit elicits and builds on students' prior knowledge and addresses common misconceptions. It is clear what references were used to build the unit, including content, teaching methods, and ideas used for adaptation. It is clear how the unit follows an instructional model (5E/7E or Learning Cycle). It is clear how the unit meets YOUR teaching goals.	The statement describes some scientific teaching information, but it needs more detail about the alignment of learning goals, assessment, activities, and diversity. References are provided without a clear description of their relevance. Some references are omitted or insufficient. Some steps of the 5E/7E model are clear, but others are ambiguous or absent.	The activities and assessments do not align with goals. References are omitted. The unit does not follow an instructional model (5E/7E or Learning Cycle).

Chapter 6
Institutional Transformation

Chapter 6

Institutional Transformation

Introduction

Many faculty who adopt scientific teaching are content to know that their teaching is based on sound principles and are not concerned with what happens in other classrooms on their campuses. But some faculty want to effect change beyond their own classrooms. Some want the respect of their colleagues and instead receive blank stares or belittling comments when they discuss their new teaching approaches. Still others need resources to buy equipment or modify their classrooms in order to implement their teaching plans, but their colleagues and administrators have no idea why these changes are needed and don't understand their value. Others would like scientific teaching methods to be used throughout a course series so that students become used to the teaching methods. Still other faculty want to share their excitement and successes with scientific teaching with colleagues to improve teaching throughout their institution. Left to their own devices, institutions of higher learning change slowly.

Institutional change has been compared with human behavioral change. Physicians have delineated the "five stages of change" that patients move through on their way to change health-related behaviors involved in smoking, eating, or exercising. The five stages are described in Figure 1.

Figure 6.1. The Stages of Change Model (Carnes et al., 2005)

Precontemplation → Contemplation → Planning → Action → Maintenance

Every campus and the individuals on it will be at different stages in the process of change. Some may be in the "precontemplation" stage, still believing that the way we teach is just fine, ("afterall, I learned a lot, didn't I?"). These colleagues will need to be convinced with different tactics and information than those colleagues in "contemplation" ("I guess I don't know that my teaching methods are effective") or "planning" ("I want to make changes, but I'm not sure how to implement active learning") stages.

Instructors and administrators often want guidance to accelerate the rate of institutional change. This chapter presents strategies for instructors and administrators to effect changes – small and large -- at the local and global levels. A few themes run through these recommendations. First, data are essential to effect institutional transformation. Evidence-based arguments are received better by scientists and are easier to defend than opinions, so it is critical to use both review articles and original studies that document the value of scientific teaching (Handelsman et al). Data collected on the campus to be transformed are especially powerful: it's hard to argue against the fact that students right there on one's own campus (not some theoretical students in the literature) are learning less than they might be if they were taught differently. Finally, enthusiasm and positive examples will propel any movement forward. It is hard to dismiss a colleague who is armed with good values about learning goals, data about student outcomes, excitement, and examples of success.

Campus-wide Policies

So often at research universities, faculty are told that teaching "doesn't matter" and they are steeped in a culture that places teaching in conflict with research. Therefore, policies, when reinforced by dedicated administrators, can transform campus values and practice, and make teaching important and reinforcing to research, rather than competing with it. For example, allocating 1/3 of merit pay increases for teaching can certainly send a message that teaching matters and is rewarded. Tenure guidelines should include strong language indicating that tenure is based in part on teaching accomplishments and guidelines for evaluation of teaching should be made available. Sabbaticals can be awarded based on plans to improve teaching, rather than on research accomplishments. Some administrators offer additional start-up funds to new faculty that are designated for teaching. These funds can be used to attend teaching workshops, purchase equipment for classrooms, or host educators from other universities to present seminars on teaching. Examples and resources for these policies are provided in Table 1.

Table 6.1. Resources to Engage Faculty in Education Reform

Policies	XX	University Examples	Resources
Merit Pay			
Sabbaticals			
Tenure Guidelines			
Start-up Funds			
Resources			
Send colleagues to Summer Institute			
Visible publications – write them and use them			

Publicity and Marketing

Administrators can use their bully pulpits to promote the integration of teaching and research and the value of teaching clearly and often. Presidents and provosts can discuss teaching in speeches, highlighting innovations and why they matter. They can instruct their campus newspaper staff to cover education topics, and feature faculty who are recognized for their research as well as teaching. Demonstrating that respected researchers are dedicated to and excel in teaching can influence other senior faculty and sends the message to junior faculty that teaching is held in high esteem by the university's most influential researchers.

Deans can allocate resources based, in part, on teaching effort and quality, providing funds to support innovation and revamping of old curricula. Department chairs can use these policies to induce their faculty to engage in teaching reform. It is essential that chairs make clear to the entire faculty that the efforts of innovators reflect well on the entire department; when the other faculty notice that their department is recognized and rewarded for teaching innovation, they are more likely to become involved in the reform movement.

Professor-to-Professor Dissemination

Most instructors who engage in education reform are eager to share their newfound knowledge with colleagues. Many are dismayed to find that their colleagues look askance at the new teaching methods and are dismissive in conversations about teaching. Changing faculty behavior is never easy. It can feel Sysiphean -- endlessly repetitive, unrewarded, and defeating. But a few strategies have been found effective, where simply telling colleagues about new techniques has failed. One of the most effective is team teaching. When colleagues see active learning in action, they can't deny its power. Students will aid the case because once they become used to active engagement, they will complain about instructors who force them back into the passive mode. Another way to engage colleagues, letting the methods speak for themselves, is to invite peer review. Most colleagues are flattered by being asked to review another's teaching and everyone benefits: the instructor being reviewed will often gain useful insights, the reviewer will see active learning in action, and the two instructors will being a useful dialogue about teaching. Finally, chairs can invite their faculty to read a book or article about teaching, such as "Leaving the Lecturn" and discuss it at a faculty meeting or faculty retreat.

Campus teaching events

Well-constructed teaching seminars and courses can be transformative. Colleagues who attend them are no doubt far along the change continuum – already in the contemplation stage or beyond and convinced that some change is needed – so this is not a strategy that will work for all colleagues. But for those who are interested and want to learn, this can be a high impact way to reach many instructors. In addition to seminars for faculty, courses for graduate students and postdocs who will be the next generation of faculty are essential ingredients in the recipe for change. In addition to developing good teaching practices themselves, they can be powerful ambassadors for change by informing their advisers and colleagues about what they are learning, thereby enlarging the pool of people affected by the course beyond just those attending it.

The following section provides materials and instructions to present a series of workshops on scientific teaching. Each workshop is designed to provide participants with experiences and discussions that model the principles that are being taught. Each workshop stands alone and can be used as a one-time seminar or workshop, or they can be taught as a series for instructors or integrated into a graduate-level course. As presented here, each workshop is intended as a 2-hour session, but they can be shortened by using either the reading assessment or the activity rather than both.

Getting participants: It's most important to start with a cohort of people who can dedicate time to most or all of the sessions. Heterogeneous groups tend to have more complex and dynamic discussions because participants draw on their collective experiences. Postdocs are often the most motivated participants.

Evaluation: Each workshop includes a short assessment to gauge what participants have learned. The survey at the end of this section is designed to gauge more extensive criteria, including participant attitudes and skills, workshop content, and the instructor.

Institutional support and future directions: Teaching evaluations of the workshops tend to be very high. They can be used for tenure/promotion packages, departmental recruiting, or campus-wide adoption of the seminar.

Workshop Structure

Time	Topic
Hour 1	Overview and Goals
	Reading Assessment
	Discussion of Reading Assessment
	Summary: Connect to Today's Topic
Hour 2	Activities (mini-lectures, cases, active learning)
	Discussion of Activities
	Summary: Connect to Scientific Teaching
	Assessment

Each workshop is designed to

- build on the collective experience and knowledge of the participants
- foster discussion among participants
- model the principles that are being discussed
- target concepts that may be difficult to understand
- help participants develop teaching skills or experience a new teaching method
- facilitate the development of instructional materials that can be used in the classroom
- cultivate a community of sharing and peer review in teaching

Overview of Workshops

Topic	Goal	Activities	Cases	Assessments
Scientific Teaching	Understand that scientific teaching includes teaching science in a way that represents the true nature of science, building a community of teachers, and teaching with the rigor of research.	Write a teaching philosophy. Share with everyone in group; read and comment collectively. Think-pair-share: What evidence would convince you that a colleague is a good teacher? Why do we teach science?	Frustrated Professor	One-minute paper: What is scientific teaching, and when have you seen it in practice?
Active Learning	Understand that students who engage in activities that challenge them are more likely to take responsibility for their own learning.	See list of EnGaugements (chapter 3) and other activities (chapter 2) Uncooking the Lab	Professor Banter. Misconceptions	Exit card: Write one sentence about a core concept in your area that students struggle to understand. Reframe it as an activity students could do.
Assessment	Understand that assessment drives student learning, it is more than grades, and it provides feedback to both instructors and students about learning.	Establish learning goals for one core concept. What will students know, understand, and be able to do at the end of the unit? How will this be measured? Design part of a rubric.	Frustrated Students It's Not Graded	One-minute paper: Explain how an assessment technique can both engage students in learning and provide them with feedback about their own understanding.
Diversity	Understand the importance of using a variety of teaching methods and tools to teach myriad students. Understand how brain acquires new information, that the process is idiosyncratic and culturally mediated, and that emotion plays an important role in learning.	Role playing: the “difficult” student. Read data about brain—how new neural networks develop through experience and cognitive dissonance, which is learning. Apply to instructional design	Cousins Vang Creating an Inclusive Classroom Environment Apathetic Studen	Exit card: List three strategies to create a more inclusive classroom.
Institutional Transformation	Understand the importance of building a community of support in teaching and learning, leveraging administrative support, and gaining/ giving recognition for teaching accomplishments.	Outline a plan to implement transformation in your department or campus.	Teaching Evaluations Mid-career Motivations	Exit card: List three allies in teaching. How can they support your teaching in the future? How can you support them?

Key Concepts and Common Myths

about Scientific Teaching

Topic	Key Concepts	Common Myths
Scientific Teaching		Inquiry is learned in graduate school; it's not appropriate for undergrads. Scientific teaching requires extensive understanding of educational literature and assessment techniques. If I'm not lecturing, I'm not teaching.
Active Learning		Active learning takes too much time and occurs at the expense of learning content. Content must be "covered" at all costs. Other goals are secondary and irrelevant. Content is irrelevant; other goals matter more, such as student attitudes, inquiry, and group skills. Students are empty vessels/slates. If I'm not lecturing or they're not taking notes, they're not learning.
Assessment		Assessment tells the instructor what students have learned; the point of assessment is not to help students learn. I know I'm successful; the students who return say they remember my teaching and how it affected them.
Diversity		Students all learn the same, like me. Students should be motivated to learn. It's the student's job to achieve, not mine. Culture, ethnicity, gender, and background have no place in the classroom. It's simply about the facts and learning them.
Institutional Transformation		There are too few people with too little time to make real change at this campus. Student evaluations are the most important measure of teaching success on my campus.

Readings

Topic	Reading (ST chapter)	Reading (not ST)
Scientific Teaching	1	Scientific Teaching (paper) Hierarchical Biology Concept Framework (Khodor *et al*.) National Science Education Standards (NRC) Bio2010 Other national reports Teaching Philosophies 101 Preparing the Job Application
Active Learning	2	
Assessment	3	Learner-Centered Assessment on College Campuses (Huba & Freed) Classroom Assessment Techniques (Angelo & Cross) Field-tested Learning Assessment Guide (FLAG) Bloom's Taxonomy The 5E/7E models (Bybee and ??) Understanding by Design (Wiggins & McTighe)
Diversity	4	They're not Dumb, They're Different (Tobias) How People Learn (NRC)
Institutional Transformation	6	

Workshop Content

Workshop I: Scientific Teaching

Goals

The goal of this workshop is to help participants understand that scientific teaching means teaching science in a way that represents the true nature of science, building a community of teachers, and teaching with the rigor of research. Scientific teaching is a process.

Activities

Hour 1: Reading assessment and summary

Hour 2: Activities and discussion

Case: Frustrated Professor

Brainstorm: Why do we teach science?

Overview of scientific teaching (mini-lecture)
- Themes: active learning, assessment, and diversity; teaching in ways that represent the nature of science; building communities in teaching; evaluating your own teaching

Think-pair-share: What evidence would convince you that students are learning the true nature of science?

Think-pair-share: What evidence would convince you that a colleague is a good teacher?

Activity: Teaching Philosophies

Examples of scientific teaching in practice

Resources, handouts, websites

Summary points:

Tips for discussion

Assessment
One-minute paper: What is scientific teaching, and when have you seen it in practice?

Case: Frustrated Professor

Share the case with participants, then discuss based on the guiding questions below. Let participants identify the issues they feel are important and share them with the group. Use their ideas to foster discussion.

"I set goals for the course and covered the content in clear, efficient lectures, but students aren't learning the material. 40% of students failed the first exam. Students these days don't know how to take notes and study. They just don't get it."

Questions to guide discussion:

1. Do you agree with the professor in this case? Why or why not?
2. Has the professor done her job?
3. Have the students done their jobs?
4. What suggestions do you have for this professor?
5. Have you faced similar challenges?
6. What challenges might the students be facing?

Summarize key points of the discussion.

Activity: Teaching Philosophies

1. Write for two minutes: *Find the statement in your teaching philosophy that you most strongly believe in. Describe what evidence shows that you have the capacity to teach in that way (or describe evidence that you would like to gain in the future).*

2. After two minutes: *Share this salient point with a partner. Discuss how your teaching philosophy and evidence (achieved or desired) applies to scientific teaching in your own career. What would you like to achieve this semester to help you as a scientific teacher?*

3. After 5-10 minutes: *Share ideas with the big group: What would you like to achieve this semester to help you as a scientific teacher?*

Suggestions for guiding participants:

As participants discuss their philosophies, circulate around the room to get a feel for what they are discussing. Refer to guiding questions for ideas. At step 3, capture answers on a black/white board or computer. As you do this, be sure to ask if you've correctly phrased the students' ideas.

Summary of the discussion:

1. Identify any common themes or interesting ideas (or ask the group to do this).
2. Key points about teaching philosophies:
   a. Your own, authentic voice should resonate in the philosophy, not educational jargon.
   b. Your teaching philosophy is an expression of your own beliefs and ideas about teaching, but each claim needs to be supported by personal examples and evidence. The examples and evidence don't have to come from classroom teaching experience; in fact, some of the most valuable pieces of evidence can be reflection on your own learning as a student (In which situations did you learn best? What would you do differently as the instructor, or what would you emulate?), or struggles you have had as a teacher (What would you do to improve next time?).
   c. Keep these early writings so you can reflect on them for session 7. Use this writing to help guide what evidence you would like to collect in the next 7 weeks, or in the coming years.

Workshop II: Active Learning

Goals

The goal of this workshop is to help participants understand that students who engage in activities that challenge them are more likely to take responsibility for their own learning

Activities

Hour 1: Reading assessment and summary

Hour 2: Activities and discussion

Case: Professor Banter

Case: Misconceptions

Overview of active learning (mini-lecture)
- **Themes**: Active learning can engage students in many ways, through inquiry, group activities (think-pair-share), discovery, online tutorials, or physical manipulation of models. Whatever the teaching method, the goal is to engage students in learning.

Activity: Uncooking the Lab

Examples of active learning in practice (see chapter 2)

Resources, handouts, websites—Uncooking the Lab

Summary points

Tips for discussion

Assessment

Exit card: Write one sentence about a core concept in your area that students struggle to understand. Reframe it as a single-sentence challenge that students could address, a problem they could solve, or a situation to be evaluated.

Case: Professor Banter

I use active learning in my class, especially for the really difficult biochemical concepts, but most of my students either won't participate or they don't get the material. I ask them questions all the time in lecture—every minute or two—to engage them. I think it makes me seem friendly and open to hearing their ideas. Sometimes I have them work in groups, but not many of them participate in that, either. I hear many of them talking about plans for Friday night or what happened on the latest episode of "Lost". Besides, the group exercises really take away from covering the lecture material. Frankly, I feel like active learning is just too much trouble, and I should try to cover more content.

Case: Misconceptions

After spending over a decade at Midwestern research universities as an undergraduate student, graduate student, and postdoc, you've landed your dream job as a faculty member at a small, private college in Georgia. The college is thrilled with your teaching experience as an HHMI Teaching Fellow at the University of Wisconsin-Madison. Of the six biology faculty, two are anxious to see your innovative teaching techniques shine in the classroom, but the other four would prefer you used more traditional teaching techniques. You are assigned to teach three undergraduate courses in the fall: first-semester introductory biology with two, 3-hour labs each week; a sophomore-level course in genetics; and an upper-level course in soil microbiology with a 2-hour lab each week. For the introductory biology course, you design the syllabus using four teachable units that are based on cases you created or adapted. You expect students to work in groups to solve each case over a 3-4 week period outside of class, in addition to lectures, online assignments, and labs.

The students seem to really enjoy the course and readily participate in the active learning exercises in lecture, so you are surprised on the first exam when the average score is a 53%. Most students did the worst on the evolution section of the exam. For example, you asked the following question:

Explain how bacteria become antibiotic resistant.

Over 75% of the students responded that "the antibiotic caused the bacteria to mutate so it could survive."

What happened? What would you do?

Activity: Un-cooking the Lab

Demonstrate an inquiry-based lab that requires groups to collaborate to develop a testable hypothesis and design an experiment. Next, demonstrate the same lab in a traditional, "cookbook" format. Let participants engage in most of each lab, then brainstorm what they experienced as students and what they think they learned.

Compare and contrast the two. (See handout, "Uncooking the Lab.") Ask participants to describe what they experienced in the role of student, and what they think students would learn from each lab. List these visibly for everyone. Discuss common themes and differences. What are the benefits and costs of each?

Example lab: Ice Nucleation
http://scientificteaching.wisc.edu
Click on "products"

Workshop III: Assessment

Goals

The goal of this workshop is to help participants understand that assessment drives student learning, it is more than grades, and it provides feedback to both instructors and students about learning.

Activities

Hour 1: Reading assessment and summary

Hour 2: Activities and discussion

Case: Frustrated Students

Case: It's Not Graded

Overview of assessment (mini-lecture)

- Themes: Assessment drives student learning, provides feedback to both instructor and student about learning, and is more than grades. Assessment that is integrated into regular classroom activities is possibly the most effective way to foster student responsibility for learning.

Activity: Establish learning goals for one core concept. What will students know, understand, and be able to do at the end of the unit? How will this be measured?

Activity: Establish clear criteria for a core concept: Develop a rubric.

Activity: Compare and contrast two assessments: Assessment worksheet.

Examples of assessment in practice

Resources, handouts, websites

Summary points

Tips for discussion

Assessment

One-minute paper: Explain how an assessment technique can both engage students in learning and provide them with feedback about their own understanding.

Case: Frustrated Students

Students complain that the exam wasn't fair because they had to apply their knowledge to a novel situation, which they hadn't done prior to the exam.

Case: It's Not Graded

Students don't do the pre-class assessments because they are not graded.

Activity: Develop a rubric

Discuss:

1. **True or False:** Evaluating students' work before it is completed is a huge waste of time.
2. What is a rubric?
3. How can a rubric foster a student-centered classroom without lowering standards of excellence?

Activity:

The rubric below uses undefined terms, value-laden terms, or comparative terms that don't provide much information to students about what they are expected to know, understand, or be able to do; about what level of performance is expected of them; or about the consequences are for not completing part of the activity.

	Excellent	**Good**	**Poor**
Understand the role of mutation in evolution	Complete and accurate description	Incomplete or partially inaccurate description	No description

Convert the rubric into statements that accurately describe the qualities you want students to achieve. Feel free to work with a partner or use reference material as needed. Refer to chapter 3 (Assessment) for more details about how a well designed rubric can enGauge students.

Criteria	**Levels of Achievement**		

Discuss:

1. Why is it better to use specific, qualitative statements over more general descriptions?
2. Other than rubrics, what other assessments tools do you plan to use for your unit?
3. **Scientific teaching:** How can rubrics help you to evaluate progress toward your own teaching goals?

Activity: Assessment worksheet

Below is a set of questions about assessment, with examples of assessment activities that emphasize either factual recall or conceptual application of knowledge. Answer the questions individually, then work with a partner to discuss your answers.

Consider the questions in chapter 3 in evaluating your own assessment tools.

	Case 1: All students are assigned a reading. Each week, each student takes a quiz that tests factual knowledge and recall.	Case 2: All students are assigned a reading. Each week, a pair of students is responsible for assessing the rest of the students' understanding of and ability to apply the readings to a new situation.
What does the assessment motivate students to do?		
How does the assessment motivate students to learn the material?		
Does the assessment give students feedback about what they know and how well they understand this topic?		
What is the consequence if the student doesn't understand the material?		
How might the students feel about taking the initiative to figure out the parts they don't understand?		
Is this assessment inclusive to everyone?		
Who is responsible for assessing student learning?		
Does the assessment encourage students to work together and provide constructive criticism to each other?		
Does the assessment align with the learning goals?		
Is the assessment consistent with the teaching goals?		

Workshop IV: Diversity

Goals

The goal of this workshop is to help participants understand the importance of using a variety of teaching methods and tools to teach myriad students, and to understand how the brain acquires new information, that the process is idiosyncratic and culturally mediated (and therefore unique for every person, and different at different times), and that emotion plays an important role in learning.

Activities

Hour 1: Reading assessment and summary

Hour 2: Activities and discussion

Activity 1: Role playing: the "difficult" student.

Case: Cousins Vang

Case: Apathetic Student

Case: Creating Inclusive Classroom Experiences

Overview of diversity (mini-lecture)

- Themes: every student brings unique experiences and worldviews to the classroom. Learning will occur when these views are challenged. New neural networks are formed when the brain is challenged to explain new information.

Examples of diversity in practice

Resources, handouts, websites

Summary points

Tips for discussion

Assessment

Exit card: List three strategies to create a more inclusive classroom in a class that you teach.

Case: Cousins Vang

I've taught introductory biology for three years now. A lot of the grade is based on written answers, such as lab reports and short-answer essay exams.

I've noticed that every semester I have two or three students whose last name is Vang. When I asked one of the students if they were related to each other, she said, "We're cousins." When I looked back at the grades for the past three years, I realized that no student with the last name Vang has received a grade higher than a C in my class. In fact, half of them have failed the course. I'm horrified! And I'm worried that I have some terrible, racist behavior that I don't know about. The students seem to understand the material when I'm talking with them, yet their written answers tend to be unclear and often miss the point. What can I do?

Case: Apathetic Student

A student, who you know is a first-generation student from rural Wisconsin, appears unmotivated during lectures. As her teaching assistant, you are concerned that she isn't engaged in learning. So you ask the professor for advice. She tells you, "Success is a choice. If she chooses not to work in this class, it's her problem." Do you agree with the professor? Why or why not?

Case: Creating Inclusive Classrooms and Learning Experiences
(THIS IS A CIRTL ACTIVITY—NEED PERMISSION)

A report was written by the LEAD Center in June 1998, entitled, *Minority Undergraduate Retention at UW-Madison: A Report on the Factors Influencing the Persistence of Today's Minority Undergraduates*. Read the excerpt below, then answer the questions on the back side of this page.

EXCERPT FROM REPORT

Another factor was how UW's white undergraduates reacted to [minority student] presence. [I]t was the reaction of the white students that was most troubling to them and served to intensify their feelings of not belonging at the university (p.25).

> *It wasn't so much that the professors made the class hard, it was the study groups and stuff....Sometimes you're not even invited into the study groups. Or you ask them and they act uncomfortable. One day I was standing in the hallway and there was this group of white kids talking, and they basically said that the only way you come to this school as a black kid is if you're on an athletic scholarship of if they lowered the standards for you. And I was just like, whatever, I didn't even care. And then I thought to myself, "Okay, no matter how unaware you are, you should know better than to say that." …And that's the kind of attitude you deal with a lot of times in this school. You don't even want to ask them to study with you. Or like, in my Spanish class last semester: the first day of class, I sit in the first seat closest to the door, and these white kids were breaking their necks to get as far away as they could. And the seat next to me did not fill up, the most convenient are right there next to me. It didn't fill until all the other seats filled. I mean, it kind of hurts my feelings, but it happens in all your classes, so you get used to it. I'm always guaranteed to have two seats next to me open, unless one of my black friends is in my class.*

The problem is not just that the overwhelming majority of undergraduates at UW-Madison are white, but that so many of them are racially uneducated whites from all-white communities. The interviewees who discussed prejudiced reactions from classmates generally believed the problem is more one of ignorance than of outright interracial hostility.

Reaction and discussion questions

1. What is your first reaction to reading this excerpt?
2. If you witness these types of student-to-student interactions in your classroom, how might you, as an instructor, respond?
3. Despite your best efforts to make your time in class as inclusive as possible, much of a student's learning occurs outside the classroom. As an instructor, what is your role in creating an inclusive learning environment outside the classroom?
4. Can you relate to any of the student behaviors or reactions in the excerpt? What are they?

Workshop V: Institutional Transformation

Goals

The goal of this workshop is to help participants understand the importance of building a community of support in teaching and learning, leveraging administrative support, and gaining/ giving recognition for teaching accomplishments.

Activities

Hour 1: Reading assessment and summary

Hour 2: Activities and discussion

Case: Teaching Evaluations

Case: Mid-career Motivation

Overview of institutional transformation (mini-lecture).

- Themes: One person can effect change. It's important to build a community of support in teaching, demonstrate and document excellence and innovation in teaching, and know the stages of change.

Activity: Outline a plan to implement transformation in your department or campus.

Examples of institutional change in practice

Resources, handouts, websites

Summary points

Tips for discussion

Assessment

Exit card: List three allies in teaching. How can they support your teaching in the future? How can you support them?

Case: Teaching Evaluations

Professor Innovative tried new teaching techniques but got poor student evaluations. At the end of the semester, the curriculum committee flagged the department chair to review his performance. What advice would you give Professor Innovation?

Case: Mid-career Motivation

Professor Mediocareer wants to try some new teaching techniques, but the department chair, Professor Luddite, and some key senior faculty don't support teaching innovations. What advice would you give Professor Mediocareer? What if she h

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