

tions are inconsistent with Darwin's findings. The resulting conflict can serve as the basis for constructing new knowledge.

### Enhance 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 (Okebukola 1986a, Little Soldier 1989, Hewitt and Seymour 1997). We should challenge 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. The traditional competitive, fact-oriented classroom does not promote deep learning for many people; moreover, this learning environment appears to be less effective, on average, for women than for men. Active learning strategies in the science classroom can be readily designed to include women as active contributors within a learning environment of interaction and collaboration. In addition, teachers who have applied these methods have found that what works well for women also works for many men, minorities, and students who typically feel alienated and disempowered in the science classroom (Rosser 1990).

## Active Learning in Practice

Many instructors would like to build an active classroom but lack specific strategies to confront the everyday situations and surprises that arise. Many comment that they would like to involve the students in discussion, but the students simply will not talk. Other instructors 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 daily classroom management.

### Group problem solving

The simplest method to engage students actively 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 students for four 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. If this approach is used, it is essential to start the reporting process with groups from a different part of the classroom each time the exercise is used so that all groups have the opportunity to report their results over the course of the semester.

Content matters, and group problem solving can help students understand the content better. It's not difficult to take a statement from a lecture and convert it to a group problem-solving exercise. What is harder is deciding which concepts are important enough to warrant the extra attention. Convenient formulations of group problems involve aspects of the scientific method. Student 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. Another effective version of group problem solving is known as "think-pair-share." Students first think individually for a minute then share and discuss their ideas with a partner. Next, they share their collective answers with the entire class. Table 2.1 provides examples for converting lecture material from passive to active.

### 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. The responses can be projected for everyone to see. Clickers can provide an immediate measure of the students' conceptual understanding. They offer the opportunity to test understanding before and after an explanation or exercise, enabling the students to assess the trajectory of their own learning. William B. Wood at the University of Colorado (2004) says about clickers:

Like any technology, these systems are intrinsically neither good nor bad; they can be used skillfully or clumsily, creatively or destructively. However, they can produce results that are eye-opening and potentially of great value to both stu-

dents and instructors for enhancing the teaching-learning process. . . . The use of clickers can lead to a substantial increase in student active engagement during class . . . to obtain valuable real-time feedback on concepts that students have difficulty with. The give-and-take atmosphere encouraged by the use of clickers in our experience makes the students more responsive in general, so that questions posed to the class as a whole during a lecture are much more likely to elicit responses and discussion.

It is essential that instructors learn the system before using it in the classroom. This technology is still new and students tend to be enthusiastic about it when it works, but they are impatient when technological bugs need to be worked out (Hatch *et al.* 2005). Many other technologies are available for instructional use and are described in DeHaan (2005).

**Brainstorming**

Presenting a broad, open-ended problem for the whole class to discuss and solve is an effective way to 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 enhances learning and gives students a sense of contributing substantively to the course content. A modified version can be done with electronic submissions prior to class, so the next class period can begin with a discussion of the brainstorm results.

**Examples of Collective Brainstorming Challenges**

- ▶ 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 . . . ?

**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

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

Concept	Passive Lecture	Active Lecture
<b>Differential gene expression</b>	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, why do different parts of the plant look different? Work with a neighbor to generate a hypothesis.
<b>Differentiation among tissues</b>	Different vascular tissues in plants have different functions. Xylem is mostly a passive transport system that moves water absorbed by the roots. Phloem is a more active system that requires ATP to carry sugars from the leaves and stems to other plant tissues.	In plants, water moves away from the roots to other plant structures through the xylem—often against gravity—but the process does not require ATP like sugar transport in phloem. Generate a hypothesis to explain how this can happen.
<b>Structure of DNA</b>	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.
<b>Decision making</b>	Many people have concerns about genetically modified organisms. Some of these concerns are well founded and others are not. You have to decide for yourself.	Split the class into two groups for a debate. One group will brainstorm about the potential of genetically modified organisms to be used for beneficial purposes and the other group will discuss possible harm.
<b>Data analysis and interpretation</b>	Based on the data shown in this slide, researchers concluded that <i>Serratia</i> <i>infernus</i> is the causal agent of the disease.	Consider 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 the results.

answers to the questions are short (short enough to fit on a 3 × 5 inch index card), they provide a way for students to gain regular writing practice without adding a huge reading burden for the instructor.

A class routine can be established so that students pick up class handouts and an index card on their way into class. They drop off their index cards in boxes marked with their lab or discussion section 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.

### One-Minute Questions

#### Reflection on learning

- ▶ 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?

#### Critical thinking

- ▶ 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.

The answers to these questions can be illuminating to both students and teachers. The simple act of reflecting on them and writing down the answers may lead students to realize that they should review the 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. Other questions can encourage critical thinking and show students the relevance of biology and its connections to their everyday lives.

#### 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. Students are given the steps in a process on strips of paper (or the virtual equivalent) that are jumbled (Figure 2.3). The challenge for the students in class is to work together to reconstruct the proper sequence. Making logical connections helps the students dissect and reconstruct the process, improving understanding. Alternative versions of strip sequences use pictures or involve students in creating the strip sequences from a textbook.

<b>Cut into strips on lines, mix the strips, and instruct students to reassemble them in the correct order.</b>
The first step in the 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.
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.

Figure 2.3 Strip sequence on gene expression

## Scientific Teaching

### Decision making

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

#### Examples of Decision-making Activities

- ▶ You are the director of the antibiotic discovery unit in a major pharmaceutical company and you are asked for 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 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?
- ▶ You are the ecologist for a land conservation trust, and your most recent project is to restore a degraded oak savanna ecosystem. As a part of your management activities, you will need to remove many of the trees and shrubs that have invaded the savanna. However, you know that many of the local landowners will have strong objections to cutting down any of the trees. How will you address the neighbors' concerns? What ecological concepts will you use to justify your plan?

### Concept mapping

Concept maps are graphic representations of the relationships between concepts. The validity of each proposition is based on the two concepts that are associated, the description that the student provides to describe their relationship, and the direction of the association.

#### Steps for Concept Maps

1. Identify the key concepts to be mapped.
2. Determine the general relationship between the concepts and arrange them two at a time on a piece of paper. The proposed relationship between the concepts is the "proposition."
3. Draw an arrow from one concept to another and then describe the relationship in a short phrase next to the arrow. The relationship should be read in a sentence in the direction of the arrow. For example, two concepts, "chloroplast" and "chemical energy," are joined by the phrase "produces." The arrow would be drawn from chloroplast to chemical energy, and the phrase would read, "Chloroplast produces chemical energy."

Since they were first developed in 1972 at Cornell University, concept maps have been shown to enhance learning and development of higher-order thinking skills (Novak and Canas 2006). 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. In addition, concept maps illustrate that there can be many different ways to represent the relationships among concepts, underscoring the value of a diversity of approaches to thinking in science.

### Concept maps redux: Mini-maps

Concept maps make evident to students the diversity of approaches to complex problems. Mini-maps embrace the idea of concepts maps, but they are much simpler to execute in the classroom. Their advantage is that they can be done in

nearly any type of classroom—including large lectures—with concepts at any level of difficulty. In addition, they provide immediate feedback about what students understand. Students are free to discuss their reasoning and work with instructors and classmates to identify misconceptions as they come to consensus about how the terms relate to each other.

Mini-maps are graphic representations of a concept or idea, using a set of related terms (usually 10 or fewer).

#### Steps for Mini-Maps

1. The instructor provides a list of terms, which can include major concepts, specific terms, or even a red herring that doesn't belong. Students write the terms on individual pieces of paper or notecards.
2. Students work in groups of 3–5 to arrange the terms in a logical structure. The relationship between terms needs to be explained with directional arrows that include a word or phrase.
3. While students are developing the mini-map, instructors interact with the groups and ask students to articulate their logic in determining the relationship among terms, or ask a few groups to explain their map to the rest of the class.

### Cases and problem-based learning

Case-based and problem-based learning present students with “real-life” situations or examples to which they must apply their factual or content knowledge. Both are designed to promote higher-order critical thinking more than factual recall. These methods demonstrate the relevance of course content to situations beyond class contexts, making facts and concepts easier to learn and retain.

The differences between problem- and case-based learning, however subtle, are meaningful, and understanding them can help instructors choose the appropriate method. Problem-based learning poses a specific question or puzzle that must be solved in order to reach a particular goal (Allen and Duch 1998, Duch *et al.* 2001). As part of solving these puzzles, students must first assess what they already know and determine what in their arsenal of knowledge is relevant or useful in solving the problem. The complexity of the problem itself becomes the means of organizing learned material, thus reinforcing students' knowledge and bolstering their confidence in their understanding of course material. The limits

of the students' knowledge becomes the basis for further learning because students identify areas in which they need additional information to solve the initial problem, locate sources that may be of use, and integrate the new information with what they already know. Problem-based exercises therefore encourage self-evaluation and research along with factual recall and application.

Case-based learning also presents specific, real-world situations that students must evaluate before applying their knowledge and formulating an answer (Wareman and Stanley 2005). In contrast to problem-based scenarios, however case-based situations and questions are open-ended. They typically do not have one single correct answer, and the complexity of the answers (not the problem themselves) becomes the means by which students assess and evaluate their understanding of both the course content and the case at hand. In case-based learning, students are asked to make a decision based upon the description of the case and their existing knowledge. Students must decide if they have enough information to make an informed decision, but also must consider what broader impact their decisions may have. What issues are at stake in the case at hand? Who might be affected—either positively or negatively—by the decision, and how might that knowledge influence the final outcome? Such questions require students to think beyond the immediate context of the case (*e.g.*, the course setting and their grade) and demonstrate how scientific knowledge is an essential part of creating policy or resolving complex issues.

An exception to the open-ended cases are diagnostic cases, used frequently in health and medical fields. For example, Harvard Medical School has used on-line case studies in its toxicology courses. Students are asked to make a diagnosis, choose a treatment plan based on a battery of vital statistics, patient history and diagnostic cues. While these cases often have one correct answer, they present students with critical, constructive explanations of answers both incorrect and correct.

### Management for the Active Classroom

#### Start early

It is important to set the tone early in the semester. If the students receive a clear message that they are expected to be active members of the classroom, a