A Framework for Scientific Teaching

	Students Think Like Scientists	**Teachers Teach Like Scientists**
Goals and Outcomes	Students experience the nature of science, including discovery, inquiry, and experimentation. Students learn the skills and knowledge relevant to the discipline	Teacher sets learning goals that represent the nature of science.
Assessment and Evaluation	Students learn to think critically and gauge their own learning; they know what criteria indicate successful learning.	Teacher sets clear criteria that establish the intended learning outcomes and determine how to measure learning.
Activities	Students engage in experiences that help them achieve the learning goals.	Teacher designs activities to help students achieve the learning goals.
Alignment	Students learn how to use feedback to monitor learning and adjust behavior accordingly.	Teacher determines whether the activities help students achieve the learning goals and whether the assessments effectively measure achievement. Teacher uses feedback from assessments to revise instruction.
Diversity and Collaboration	Students learn to work in groups and learn how to include a diversity of students in the process.	Teacher uses a variety of teaching methods to engage a diversity of students. Teacher discusses teaching methods, instructional materials, student diversity, and evaluation results with colleagues.

Source: "Scientific Teaching," Jo Handlesman, Sarah Miller, and Christine Pfund. W. H. Freeman and Company. New York, NY. 2007.

Definitions and Common Myths about Scientific Teaching

Topic	Definition	Common Myths
Scientific Teaching	Teaching science in a new way that represents the true nature of science and approaches teaching with the rigor of scientific research.	Scientific teaching requires extensive understanding of educational literature and assessment techniques. Undergraduate students are not sufficiently sophisticated to understand scientific inquiry; inquiry is learned in graduate school. If I'm not lecturing, then I'm not teaching.
Active Learning	The process in which students are actively engaged in learning.	Active learning takes too much time and occurs at the expense of learning content. I have to cover the content for the next course. Content must be covered at all costs. Other goals are secondary or irrelevant. As long as students are busy, they're thinking. Students' minds are empty vessels or blank slates. If students are not taking notes, then they are not learning.
Assessment	Measuring progress toward and achievement of the learning goals.	The point of assessment is not to help students learn-the point is to measure what they have learned. I know I'm successful; the students who return say they remember my teaching and how it affected them. I don't have the background in assessment needed to be a scientific teacher.
Diversity	The characteristics that make each student unique, and each teaching experience unique. Diversity includes everything in the classroom: the students, the instructors, the content, the teaching methods, and the context.	Students should learn to study the way I did. Students should be self-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 learning the facts.

Key Concepts in Scientific Teaching

Scientific teaching refers to **teaching science** in a way that represents the true nature of science and to the **science of teaching**.

- A scientific teacher sets learning goals that represent the complex nature of science.
- A scientific teacher chooses activities that engage a diversity of students in thinking and behaving like scientists.
- A scientific teacher evaluates learning regularly and makes teaching decisions based on evidence.
- Scientific teaching involves building a community of teachers.
- Scientific teaching is an iterative process of review and revision.
- Active learning, assessment, and diversity are core themes of scientific teaching.

Key Concepts in Active Learning

Active learning engages students in thinking and behaving like scientists

- Students learn when their current views (prior knowledge and misconceptions) are challenged by new information, and they have to construct new explanations to account for the information.
- Active learning provides a model of how scientists think and behave.
- Students who engage in challenging activities are more likely to take responsibility for learning.
- Group process and cooperation are integral components of active learning.
- Experimentation is the best way to engage students in active learning and it can easily be done in lecture or lab.

Key Concepts in Assessment

Assessment drives student learning, it can be used to create an inclusive classroom, it is more than grades, and it provides feedback to both instructors and students about learning.

- Regular classroom assessment is one of the most effective ways to engage students in learning.
- Assessment tools and active learning exercises can be the same thing; together, they simultaneously engage students in learning and gauge their learning.
- Results from assessments can be used to evaluate student learning, evaluate teaching, and guide changes in student behavior and instruction.

Key Concepts in Diversity

Diversity affects learning through the knowledge, experience, and cultural influences that make each student unique; through the teaching methods, examples, and content we choose to use; and through the biases and assumptions that everyone brings to the classroom.

- Diversity is essential for progress in science.
- Every teaching situation is unique and every student is unique.
- Learning is idiosyncratic and culturally mediated (and therefore unique for every person, and different at different times)
- Every person brings biases and assumptions to the classroom.
- A variety of teaching methods can reach more diverse students.

Source: Handelsman, J., S. Miller, C. Pfund. 2007. *Scientific Teaching*. New York: W.H. Freeman & Co.

Suggested Reading

Scientific Teaching

- Handlesman, J., D. Ebert-May, Beichner, P. Bruns, A. Chang, R. DeHaan, J. Gentile, S. Miller Lauffer, J. Stewart, S. M. Tilghman, and W.B. Wood. 2004. Scientific teaching. *Science* 304:521-522.
- National Research Council. 2003. *Bio2010: Transforming undergraduate education for future research biologists.* Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, Board on Life Sciences, Division on Earth and Life Studies. Washington, D.C.: National Academies Press.

Active Learning

- DeHann, R. L. 2005. The impending revolution in undergraduate science education. *Journal of Science Education and Technology* 14: 253-269.
- National Research Council 1999a. *How People Learn: Brain, Mind, Experience, and School.* Commission on Behavioral and Social Sciences and Education. Washington, D.C.: National Academies Press.
- National Research Council 1999a. *How People Learn: Bridging Research and Practice.* Commission on Behavioral and Social Sciences and Education. Washington, D.C.: National Academies Press.

Assessment

- Angelo, T.A., and K.P. Cross. 1993. *Classroom Assessment Techniques: A Handbook for College Teachers*. San Francisco: Jossey-Bass.
- Huba, M.E., and J.E. Freed. 2000. *Learner-Centered Assessment on College Campuses: Shifting the Focus from Teaching to Learning*. Needham Heights, MA: Allyn & Bacon.
- National Institute for Science Education, C. L. O. C.-T. 1999. *Field-Tested Learning Assessment Guide (FLAG)*. Madison, WI: Wisconsin Center for Educational Research. http://www.flaguide.org
- National Institute for Science Education, C. L. O. C.-T. 1999. *Student Assessment of Learning Gains (SALG)*. Madison, WI: Wisconsin Center for Educational Research. http://www.salgsite.org/
- Wiggins, G., and J. McTighe. 1998. *Understanding by Design*. Alexandria, VA: Association for Supervision and Curriculum Development.

Diversity

- Women in Science and Engineering Leadership Institute. 2006. http://wiseli.engr.wisc.edu/
- Diversity Institute, Center for the Integration of Research, Teaching, and Learning. 2006. http://cirtl.wceruw.org/diversityinstitute

Assessment Activity
Read the example test questions and determine which of Bloom's levels of understanding is necessary to answer the questions.

Chapter 31: Fungi - *Campbell's Biology, 9e* (Reece et al.)

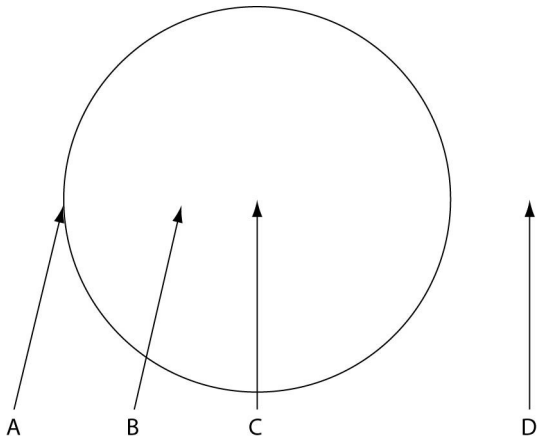
1) *All* fungi share which of the following characteristics?
A) symbiotic
B) heterotrophic
C) flagellated
D) pathogenic
E) act as decomposers

2) Which process occurs in fungi and has the opposite effect on a cell's chromosome number than does meiosis I?
A) mitosis
B) plasmogamy
C) crossing over
D) binary fission
E) karyogamy

Question 3 refers to the following description:
For several decades now, amphibian species worldwide have been in decline. A significant proportion of the decline seems to be due to the spread of the chytrid fungus, *Batrachochytrium dendrobatidis* (Bd). Chytrid sporangia reside within the epidermal cells of infected animals, animals that consequently show areas of sloughed skin. They can also be lethargic, which is expressed through failure to hide and failure to flee. The infection cycle typically takes four to five days, at the end of which zoospores are released from sporangia into the environment. In some amphibian species, mortality rates approach 100%; other species seem able to survive the infection.

3) When adult amphibian skin harbors populations of the bacterium, *Janthinobacterium lividum* (Jl), chytrid infection seems to be inhibited. Which of the following represents the best experimental design for conclusively determining whether this inhibition is real?
A) Inoculate uninfected amphibians with Jl, and determine whether the amphibians continue to remain uninfected by chytrids.
B) Inoculate infected amphibians with Jl, and determine whether the amphibians recover from infection by chytrids.
C) Take infected amphibians and assign them to two populations. Leave one population alone; inoculate the other with Jl. Measure the rate at which infection proceeds in both populations.
D) Take infected amphibians and assign them to two populations. Inoculate one population with a high dose of Jl; inoculate the other with a low dose of Jl. Measure the survival frequency in both populations.

Questions 4 and 5 refer to the following description:
The following figure depicts the outline of a large fairy ring that has appeared overnight in an open meadow, as viewed from above. The fairy ring represents the furthest advance of this mycelium through the soil. Locations A-D are all 0.5 meters below the soil surface. Responses may be used once, more than once, or not at all.



4) What is the most probable location of the oldest portion of this mycelium?
A) A
B) B
C) C
D) D

5) Assume that all four locations are 0.5 m above the surface. On a breezy day with prevailing winds blowing from left to right, where should one expect to find the highest concentration of free basidiospores in an air sample?
A) A
B) B
C) C
D) D

6) You are given an organism to identify. It has a fruiting body that contains many structures with eight haploid spores lined up in a row. What kind of a fungus is this?
A) zygomycete
B) ascomycete
C) deuteromycete
D) chytrid
E) basidiomycete


Meaningful Learning
Rote Learning
Creating
Combining information to form a unique thesis, concept, or product - requiring creativity and originality. Putting elements together to form a coherent or functional whole; reorganizing elements into a new pattern or structure through generating, planning, or producing.
Key ideas: Design, Hypothesize, Invent, Develop, Compose, Estimate, Theorize, Elaborate, Test, Improve, Invent, Originate
Evaluating
Making decisions and supporting views - understanding of values, judging the validity of ideas or quality of work based on a set of criteria, having a profound understanding of the discipline. Making judgments based on criteria and standards through checking and critiquing.
Key ideas: Judge, Critique, Justify, Recommend, Criticize, Assess, Disprove, Rate, Resolve
Analyzing
Identifying components - determining arrangement, logic, and semantics to identify organizational structure. Breaking material into constituent parts, determining how the parts relate to one another and to an overall structure or purpose through differentiating, organizing, and attributing.
Key ideas: Analyze, Categorize, Separate, Dissect, Simplify, Deduct, Infer
Applying
Using information to solve problems - transferring abstract or theoretical ideas to practical situations, identifying connections and relationships and how they apply. Carrying out or using a procedure through executing or implementing.
Key ideas: What if, Use, Compute, Solve, Demonstrate, Apply, Construct, Build, Experiment
Understanding
Restating in your own words - paraphrasing, summarizing, translating. Constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarizing, inferring, and explaining.
Key ideas: Why, How, Explain, Paraphrase, Describe, Illustrate, Compare, Contrast, Interpret, Outline, Map, Rephrase
Remembering
Memorizing information verbatim - retrieving, recognizing, and recalling relevant knowledge from long-term memory.
Key ideas: What, Remember, List, Label, State, Define, Choose, Find, Select, Match

Diversity Worksheet: Creating an Inclusive Classroom

Work with a partner to identify strategies to make each situation more inclusive.

Teaching method or instructional choice?	**Who might feel excluded?**	**What could be done to make the classroom more inclusive?**
Lectures are done with PowerPoint exclusively; the slides are dense with information. Notes are not available to students		
Historical examples always involve white men		
Examples always involve American people and situations.		
Exams are entirely multiple-choice and true-false.		
Exams are timed. Students are cut off after 2 hours. Grades are based on a curve.		
Homework assignments are only available online.		
The textbook costs $120.00		
The class meets at 7:30 in the morning.		
Class requires students to work in assigned groups weekly, outside of class time.		

Worksheet from "Scientific Teaching," Jo Handlesman, Sarah Miller, and Christine Pfund. W. H. Freeman and Company. New York, NY. 2007.