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Feature

Approaches to Biology Teaching and Learning

A Portal into Biology Education: An Annotated List of Commonly Encountered Terms

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In an introductory biology course, undergraduate students are expected to become familiar with, and be able to use, hundreds of new terms to navigate the complex ideas in biology. And this is just in the introductory course! Juxtapose this student situation with the common frustration expressed by biologists that there is "just too much jargon in science education." Unfortunately, a common frustration for a disciplinary novice is learning to navigate the language. For biologists venturing into the social sciences, this can be particularly tricky, as the language may at first seem easily understood, because the conjoined words are familiar—for example, "cooperative learning," "stereotype threat," or "problem-based learning." However, the meaning of these words in combination is often specialized and represents rich traditions and research literatures that go far beyond summing the dictionary definitions of the component terms.

So, how does one begin to explore the ideas and language of biology education? We have chosen 50 key terms that scientists will likely encounter in any exploration of biology education. To provide a framework for how these terms might connect together for instructors, we have used the organizing framework of *scientific teaching*, in which there is no prescribed or correct way to teach; rather, instructors are expected to apply scientific principles to their classroom teaching efforts. Scientific teaching is an intentional approach to teaching by instructors that focuses on the goal of student learning and involves iterative questioning, evidence collection, and innovation. Inspired by the original book on the subject, *Scientific Teaching* (Handelsman *et al*., 2006), we have chosen to introduce the reader to key terminology in biology education by organizing these terms with respect to the three main tenets of scientific teaching—active learning; assessment; and the related ideas of equity, diversity, and inclusivity—along with a fourth section about tools for moving the ideas of scientific teaching into practice:

Active Learning: Engaging Students as Participants in Learning
Assessment: Finding Out How Students Are Thinking and Learning
Equity, Diversity, and Inclusivity: Creating Fair and Accessible Learning Environments
Moving to Practice: Instructional Design, Learning, and Technologies

For each of these four sections, there is a brief overview of the topic, followed by a set of commonly encountered terms related to that topic. For each key term, we provide an introductory, descriptive paragraph, which is followed by two references that could be starting points for additional explorations. Whenever possible, these references include accessible review articles written primarily for a scientific audience. No doubt, dozens of additional terms could be added to each section; however, this collection is intended to be a starting point for readers. Additionally, many of the terms we have associated with one section could easily also be placed into other sections. For example, "think–pair–share" is a teaching strategy that is all at once an active-learning approach, a potential mode to assess students, and an equitable teaching strategy that can provide access and opportunity for all students to participate.

Importantly, the entries for these 50 key biology education terms may be read and explored in any order. Readers are encouraged to use Table 1 to self-assess which of these terms are familiar and most interesting. Self-assessment responses to Table 1 can guide which of the sections below you may be most interested in reading first. So, onward, and enjoy exploring the ideas and language of biology education.

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Table 1. Biology education terminology self-assessment

U=Unfamiliar
F=Familiar

Biology Education Terminology Self-Assessment

Active Learning	Assessment
___ 1. Think-Pair-Share	___ 12. Formative Assessment
___ 2. Clickers	___ 13. Summative Assessment
___ 3. Minute Paper	___ 14. Preassessment
___ 4. Group Work	___ 15. Postassessment
___ 5. Cooperative Learning	___ 16. Learning Gains
___ 6. Peer Instruction	___ 17. Closed-ended Questions
___ 7. Peer-Led Team Learning	___ 18. Open-ended Questions
___ 8. Case-based Learning	___ 19. Bloom's Taxonomy
___ 9. Problem-based Learning	___ 20. Classroom Assessment Techniques
___ 10. Student Resistance	___ 21. Grading
___ 11. Student Evaluation	___ 22. Criterion-referenced Grading
	___ 23. Norm-referenced Grading
	___ 24. Rubrics

Inclusivity, Equity, and Diversity	Moving to Practice
___ 25. Equity	___ 40. Backward Design
___ 26. Diversity	___ 41. Learning Theory
___ 27. Inclusivity	___ 42. Metacognition
___ 28. Student-Deficit Model	___ 43. Syllabus
___ 29. Achievement Gap	___ 44. Lesson Plans
___ 30. Instructional Selection	___ 45. Learning Technologies
___ 31. Stereotype Threat	___ 46. Blended Learning
___ 32. Retention	___ 47. Accessibility
___ 33. Persistence	___ 48. Universal Design
___ 34. Underrepresented Minority	___ 49. Scientific Teaching
___ 35. Students of Color	___ 50. Nature of Science
___ 36. First-Generation Students	
___ 37. Self-Efficacy	
___ 38. Unconscious or Implicit Bias	
___ 39. Equitable Teaching Strategies	

Other biology education terms I have encountered and want to explore…

ACTIVE LEARNING: ENGAGING STUDENTS AS PARTICIPANTS IN LEARNING

The first cornerstone of scientific teaching is *active learning*. As a biology education community, we have traditionally focused much of our conversation about teaching and learning on issues of "what" exactly students should be learning; however, attention is increasingly being paid to the "how" of teaching. Multiple lines of research efforts in a variety of disciplines have provided evidence that traditional lecture approaches to teaching are much less effective than teaching approaches that actively engage students in the learning process (Bransford *et al*., 1999; Handelsman *et al*., 2006; Freeman *et al*., 2014). Active-learning approaches to teaching encompass a range of strategies—from simple to complex, from activities that last just a few minutes to longer projects, from inside class time to outside class time. Common to all these active-learning strategies is the acknowledgment that learning is a phenomenon of the human brain, and the individuals doing the learning must be actively involved in constructing meaning, examining their prior ideas, and resolving conceptual confusions, just as scientists do in their own efforts to learn how the natural world works. Below, we introduce 11 key terms that biologists would likely encounter in their explorations to learn more about active learning.

1. Think–Pair–Share

The term "think–pair–share" refers to a teaching method that expects students think individually about a solution to a problem for a moment, then pair with a neighbor to share their ideas, and sometimes eventually report out to the large group (Lyman, 1981; reviewed in Tanner and Allen, 2002). In three easy steps, every student in a class of any size can be engaged in active learning through a think–pair–share. After posing a question, the instructor gives the class a few minutes to think and jot down their thoughts. This think time is key, since different students may have different cognitive processing times—our brains all work differently—and giving students more time to just think has been shown to increase the quality of comments later shared and the number of students willing to share (Rowe, 1987; Tobin, 1987). Then comes the "pair" time, a few minutes for each student to say his or her ideas out loud to another student in the class. For the vast majority of students who do not have the confidence to ask or answer questions in front of the whole class, this pair time may be the first time they have uttered a word in an undergraduate science classroom. Pair time allows students to articulate their ideas in the presence of another person; compare their ideas with those of a peer; and identify points of agreement, disagreement, and confusion. Finally comes the "share" part, in which several students are asked to share with the whole class ideas that emerged in their pair discussions. This phase should be very familiar to most instructors, since it is comparable to posing a question to an entire class. Setting up a think–pair–share activity can be as simple as posing a question or problem for students to think about and discuss, such as "Predict the outcome of this experiment," "Propose at least two hypotheses to explain these observations," or "Answer the multiple-choice question posted on this slide."

For further exploration…

1. Tanner KD (2009b). Talking to learn: why biology students should be talking in classrooms and how to make it happen. CBE Life Sci Educ *8*, 89–94.
2. Smith MK, Wood WB, Adams WK, Wieman C, Knight JK, Guild N, Su TT (2009). Why peer discussion improves student performance on in-class concept questions. Science *323*, 122–124.

2. Clickers

Clickers—also referred to as personal response systems—are devices that can be used in classrooms of any size to ask multiple-choice questions with the goal of engaging students with the course material as part of active-learning exercises. While a variety of clicker systems are available, the iClicker system has become widespread, likely because these clickers do not require integration with a particular software presentation system. While clickers can be used to check attendance, more effective uses of clickers aim to engage students in answering questions that check student understanding, challenge common misconceptions, and provide immediate conceptual feedback for both students and instructors alike. While getting students to talk does not require clickers, clicker questions can be the basis of multiple think–pair–share activities during a single class period. A key added value of using clickers is that this technological tool can give the instructor an instant summary of the distribution of student responses to a multiple-choice question. This information can immediately guide an instructor in deciding how to proceed, depending on the proportion of students who select the most scientifically accurate response. Clicker questions can be especially useful when asked a week or so before a section of the course is taught. Using this evidence from students, instructors can identify common misconceptions held by those students, plan class activities to address these misconceptions, spend less time on those ideas that students already seem to know, and, finally, share this clicker evidence with students to explain why course time is being spent on some particular topics more than others.

For further exploration…

1. Wood WB (2004). Clickers: a teaching gimmick that works. Dev Cell *7*, 796–798.
2. Smith MK, Wood WB, Adams WK, Wieman C, Knight JK, Guild N, Su TT (2009). Why peer discussion improves student performance on in-class concept questions. Science *323*, 122–124.

3. Minute Paper

A minute paper is a brief active-learning strategy that provides a mechanism for students to stop, think, and write during or at the end of a class period (Mazur, 1996). The goal is to provide a momentary break during which students can capture their thoughts or questions. While referred to as a "minute" paper, these brief writings can generally take one to several minutes, depending on the complexity of the question being asked. Often, questions that are most effective at challenging students' ideas and promoting rich discussions are not multiple choice, in which case clickers become less useful. Minute papers are often driven by these non–multiple choice questions (see *18. Open-Ended Questions*). Example minute-paper prompts might include: "What's the most useful concept or idea you learned in class today?," or "What was the muddiest point in today's class session that was most confusing for you?," or " Push yourself to write down at least two questions you have about the scientific evidence we explored in class today." Some instructors require students to purchase a 100-pack of index cards as part of their course materials to facilitate frequent use of minute papers. Students are told that during each of their class meetings over the semester, they will be asked to write down their ideas on these index cards. Most of the time, instructors will collect these cards, but sometimes they will not. A minute paper can serve as one way to accomplish the "think" phase of a think–pair–share, since it actively engages students in doing something to drive their thinking.

For further exploration…

1. Allen DE, Tanner KD (2005). Infusing active learning into the large enrollment biology class: seven strategies, from the simple to complex. Cell Biol Educ *4*, 262–268.
2. Angelo TA, Cross KP (1993). Classroom Assessment Techniques: A Handbook for College Teachers, San Francisco, CA: Jossey-Bass.

4. Group Work and 5. Cooperative Learning

Science is, by nature, a collaborative endeavor, and all scientific careers to which undergraduate students aspire will require extensive skills in working collaboratively. Group work, also referred to as cooperative learning, is a term that refers to activities that require students to engage in active learning with others, during which they work together toward a common outcome and practice improving their collaborative skills (Johnson *et al.*, 1991, 1993, 1998). To be successful, group work requires several critical elements. First, the task must be clear, with students understanding both the final goal of the activity, as well as key milestones along the way. Second, the assignment must be sufficiently complex that it necessitates collaboration. Students are clever; they know that being told to work together on a simple task is not a good use of time and will then perceive the task as busy work. As such, group sizes should reflect the complexity of the assigned task. Third, students need to know their role and the instructor's expectations of them as individuals. Roles can be assigned by the instructor, or in some special cases, students can be charged with self-organizing. Roles can be divided multiple ways, depending on the task. For example, roles can reflect group functions, such as facilitator, timekeeper/recorder, reporter, or equity monitor (the person who makes sure all group members' ideas are heard). Roles can also reflect authentic perspectives on a problem or issue, such as scientist, policy analyst, financial officer, business owner, or citizen/parent.

Finally, group work requires the establishment of trust, grounded in a set of group norms, which are guidelines for working together that may be set by the instructor or students in the course. Examples of group norms are that everyone will contribute during discussions, ideas will be respectfully shared, and work will be fairly divided among group members. Group work and cooperative learning is often assumed to include more than two students, but usually no more than six. Importantly, the larger the size of the student group, the more care the instructor must take to clearly define tasks and roles to ensure no students are left out of the group process.

For further exploration…

1. Tanner KD, Chatman LC, Allen DE (2003). Cooperative learning in the science classroom: beyond students working in groups. Cell Biol Educ *2*, 1–5.
2. Johnson DW, Johnson RT, Smith KA (1998). Cooperative learning returns to college: what evidence is there that it works? Change *July/August*, 27–35.

6. Peer Instruction and 7. Peer-Led Team Learning

The practice of students teaching students is not new and has taken many forms over the years, as teaching an idea to someone else is often an effective way to learn. Peer instruction is defined by the act of students teaching or reviewing one another. In some peer-instruction scenarios, one student becomes an "expert" on some topic and is then tasked to teach what he or she knows to other students who are novices with respect to that material. This approach is often used as an active-learning strategy for exploring large amounts of complex material in single class periods. For example, four research articles can be explored in a single class session in which one-quarter of the class has become expert on each paper through a prior homework assignment. During class time, student experts for each of the four papers then take turns sharing their insights and entertaining questions from peers. Peer instruction also refers to opportunities in classrooms wherein students teach one another without there necessarily being different levels of expertise between students (Mazur, 1996; Gosser *et al.*, 2001; Smith *et al.*, 2009). Research has shown that two students, neither of whom was able to correctly answer a clicker question, could improve their understanding and correctly answer similar clicker questions after engaging in a pair discussion, which is another form of peer instruction (Smith *et al.*, 2009). Peer-led team learning is a particular type of peer instruction, in which students who have previously excelled in a course are invited back to serve as supplementary course discussion leaders or in-class coaches for students currently taking the course. Having most recently learned the concepts at hand, these peers—sometimes called learning assistants—may be more socially accessible to students and better able to remember the kinds of confusions students encounter with the material.

For further exploration…

1. Crouch CH, Mazur E (2001). Peer instruction: ten years of experience and results. Am J Phys *69*, 970–977.
2. Mazur E (1996). Peer Instruction: A User's Manual, Englewood Cliffs, NJ: Prentice-Hall.

8. Case-Based Learning and 9. Problem-Based Learning

Case-based and problem-based learning are teaching approaches that link course concepts to real-world scenarios and problems with which students actively engage through exploring and questioning and applying biological content knowledge. While the goal is similar for each, the approaches vary slightly. Problem-based learning moves groups of students through a prescribed strategy of identifying what they already know and what they need to know, then determining how to access any additional information they need to solve a complex problem related to biology, such as determining mechanisms of gene inheritance or designing an experiment to distinguish between alternate hypotheses. Case-based learning evolved from the medical and business fields; the activities task students with figuring out the underlying causes of a medical condition or a business success. Similarly, in science instruction, case-based learning begins with a situation or scenario that poses one or more issues the students need to address. Depending on the goals of the case, students may be given more or less structure in how to resolve it. Cases can range from fairly simple (one issue, one solution) to complex, real-world scenarios that scientific researchers themselves may not yet have been able to explain. Importantly, both case-based and problem-based learning usually involve students working in structured groups in which they collaboratively identify questions and confusions and seek out additional information to expand their understanding of concepts related to the problem or case.

For further exploration…

1. Allen DE, Tanner KD (2003). Learning in context: problem-based learning. Cell Biol Educ *2*, 73–81.
2. Allen DE, Duch BJ (eds.) (1998). Thinking Towards Solutions: Problem-based Learning Activities for General Biology, Philadelphia, PA: Saunders College.

10. Student Resistance and 11. Student Evaluations

As a new instructor, student resistance—and the potential for poor student evaluations at the end of the course—can seem sufficient reason to avoid attempting active learning and becoming more innovative in the classroom. Student resistance is defined as unwillingness among one or more students to comply with instructor requests. This resistance can take the form of active resistance, including complaints to department heads or vocal refusal to participate, as well as more passive forms of resistance, such as just not following instructor directions and doing something else. Student resistance often seems to be rooted in students' prior experiences in classrooms and their expectations of what should be happening in an undergraduate science course. If students have experienced lecture throughout their school years, then their expectations may be unmet by this shift from their normal experiences when they enter a course with extensive active learning.

Student evaluations, defined as information gathered about the course or the teaching at some point during the semester, are a concern for most faculty members. For example, students may have previously experienced poorly structured active learning or group work, resulting in generally unfavorable opinions of these teaching approaches. This is where an instructor's transparency about the reasons for choosing particular teaching strategies may be critical. In addition to sharing their rationale for teaching choices, instructors can also collect student evaluations throughout the course, not just at the end. This not only provides students a voice in the teaching and learning process but also gives instructors insight into how students are experiencing the course midway, offering the opportunity for the instructor to make adjustments. Using the minute-paper method described earlier, instructors can ask each student anonymously to share responses to: "So far, what aspects of the course are most supporting your learning?" and "So far, what aspects of the course are least supporting your learning?" Even the act of inviting student insights may go far in quelling student resistance. Finally, it may be key for instructors to be quantitative in gauging the extent of student resistance and to be systematic in hearing from all students. While a few students may express resistance, the vast majority of students could deeply appreciate innovative teaching approaches, and the instructor would be unaware of this without inviting midcourse student evaluation.

For further exploration…

1. Seidel SB, Tanner KD (2013). What if students revolt?—considering student resistance: origins, options, and opportunities for investigation. CBE Life Sci Educ *12*, 586–595.
2. Tanner KD (2011). Moving theory into practice: a reflection on teaching a large introductory biology course for majors. CBE Life Sci Educ *10*, 113–122.

ASSESSMENT: FINDING OUT HOW STUDENTS ARE THINKING AND LEARNING

The second tenet of scientific teaching is assessment, which is fundamentally the act of using questions to reveal student thinking, challenge student thinking, and gauge the extent to which we are changing students' minds about how the biological world works. Importantly, assessment is the act of asking a question and receiving responses, not just from one or a few students, but from *all* students in a classroom. Unfortunately, the term "assessment" may mean a variety of different things to different people. For many biologists, assessment is inappropriately simplified to mean anything having to do with grading, exams, or quizzes. Unsurprisingly, scientists who embrace this meaning of assessment have little fondness for it. In the context of college and universities, assessment can additionally bring with it the negative connotations of external evaluation, accreditation, and penalty. Given these preconceptions, it is no wonder that many instructors avoid explorations of assessment at all cost. However, assessment evidence can be a key tool to inform decision making by instructors about what and how to teach the particular students sitting in front of them. From the educational perspective, well-designed assessments are arguably the most effective tools instructors have to foster learning in their classrooms. From a biological perspective, assessment aligns with the very nature of our discipline because assessment is essentially evidence that can inform and drive our decisions about what to do next. Continual, everyday assessment allows classroom instruction—and student learning—to evolve through a structured, iterative process of trial and error that focuses the instructor's efforts and the students' energies on those ideas that are the most challenging. We introduce here 13 key terms that biologists would likely encounter in their explorations to learn more about classroom assessment.

12. Summative Assessment and 13. Formative Assessment

A core idea often not understood about assessment is that it can both measure learning *and* drive learning. "Summative assessment" is the term used to describe assessment activities that measure or evaluate learning (Huba and Freed, 2000). Summative assessments often occur at the end of a learning experience and are often graded, examples being midterm exams and term papers. The grade provides external motivation for performance and acts as an indicator for external stakeholders to evaluate students. In contrast, "formative assessment" refers to those assessments that occur before or during the learning process and that can be instrumental in driving learning. Formative assessments provide lower-stakes, often nongraded, opportunities for students to check their understanding of a concept or practice thinking through a problem. Examples of formative assessment include minute papers, clicker questions, peer review of written drafts, quick low-stakes quizzes before class, or online tutorials with responsive feedback. Feedback plays a critical role in formative assessment, whether from the instructor, the student's own self-reflection during the assessment, or discussion of efforts with a peer. Often, the objective of formative assessment is for both instructors and students to evaluate the extent to which students understand. Formative assessments drive learning by providing regular, ongoing feedback to students and instructors about what is being learned, and may or may not be graded.

For further exploration…

1. Tanner KD, Allen DE (2004a). Approaches to biology teaching and learning: from assays to assessments. Cell Biol Educ *3*, 69–74.
2. Dirks C, Wenderoth MP, Withers M (2014). Assessment in the College Science Classroom, New York: Freeman.

14. Preassessment, 15. Postassessment, and 16. Learning Gains

As instructors innovate in their teaching approaches, assessment questions offer the opportunity to systematically collect evidence on student learning, fundamentally using our classrooms as learning laboratories. Preassessments and postassessments are simply questions asked of all students before teaching begins and after teaching has concluded. Comparison of preassessments and postassessments can provide instructors evidence about learning gains (or lack thereof), defined as the difference between the beginning and end scores over a designated instructional time period. Postassessments are generally questions posed on summative assessments, such as midterm or final exams. Preassessments offer a baseline about students' knowledge that can later be compared with postassessments to determine learning gains. More importantly, preassessments—which are woefully uncommon in undergraduate biology classrooms—can also serve other important roles for instructors. Not only can preassessments illuminate what students already know, they can also identify common misconceptions and misunderstandings held by the majority of students. For instructors, this preassessment evidence can be used to tailor the instruction to the particular conceptual challenges of that group of students. When shared with students, preassessment evidence can also focus study efforts toward those ideas. Examples of preassessments can include clicker questions, minute papers, concept maps, or a variety of other student tasks. Additionally, preassessments need not only probe conceptual understanding but can also probe motivation through a questionnaire about why students are taking the class and what they hope to get out of it or probe confidence by having students rank their confidence in their understanding of upcoming concepts. A word of caution: if preassessments are high stakes, especially if connected to grades, they may evoke personal stereotypes among some students and counterproductively impede learning (see *31. Stereotype Threat*).

For further exploration…

1. Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP (2014). Active learning increases student performance in science, engineering, and mathematics. Proc Natl Acad Sci USA *111*, 8410–8415.
2. Knight JK, Wood WB (2005). Teaching more by lecturing less. Cell Biol Educ *4*, 298–310.

17. Closed-Ended Questions and 18. Open-Ended Questions

While assessments can take many forms, they are usually questions, which are either closed-ended questions or open-ended questions. Closed-ended questions provide a finite (closed) set of response options from which the students select what they believe to be the correct answer. Examples of closed-ended questions include multiple-choice, matching, and true–false questions. One benefit of closed-ended questions, such as multiple-choice or matching questions, is that instructors can easily gauge understanding among a population of students (e.g., by using clicker questions). Additionally, closed-ended questions are more quickly graded than open-ended questions. A drawback of closed-ended questions is that—unless carefully crafted—they often assess only lower-order cognitive skills such as remembering terms and are less likely to evaluate more complex skills related to experimentation, synthesis, or communication.

In contrast, open-ended questions provide opportunities for students to compose responses in their own words. Examples of open-ended questions include essay questions, drawing or diagramming questions, or even concept maps. A key benefit of open-ended questions is that they demand students gather and synthesize their ideas and cogently express them in writing. Additionally, open-ended questions are often useful in assessing higher-order cognitive skills related to experimentation, synthesis, or communication. However, open-ended questions do not lend themselves to quick evaluation of understanding among groups of students, nor are they quick to grade. However, strategies such as peer grading or the use of rubrics to facilitate grading make asking open-ended questions tractable. Importantly, open-ended questions may be most useful in driving authentic student learning, since few real-world scientific careers offer closed-ended questions or problems.

For further exploration…

1. Allen DE, Tanner KD (2002). Questions about questions. Cell Biol Educ *1*, 63–67.
2. Dirks C, Wenderoth MP, Withers M (2014). Assessment in the College Science Classroom, New York: Freeman.

19. Bloom's Taxonomy

Bloom's taxonomy—conceived by mid–20th century educator and researcher Benjamin Bloom—is a system with which instructors can judge the nature of the assessment questions they are asking their students (Bloom *et al.*, 1956). While many have argued about and revised the original categories of Bloom's taxonomy, the core ideas persist about how to judge the type of thinking that may be elicited by an assessment question. Bloom proposed that learning could be categorized into lower-order cognitive skills (such as knowing, remembering, or describing) and higher-order cognitive skills (such as analyzing, evaluating, inventing, or synthesizing). This simple framework provides instructors with a mechanism to evaluate the extent to which their student learning objectives and their assessment tools are targeting higher-order versus lower-order student thinking.

Importantly, instructors can often judge the nature of their assessment questions based on Bloom's taxonomy by attending to the verbs used in the assessment. Lower-order assessment questions are often those that ask students to: define, list, describe, explain, summarize, or paraphrase. In contrast, higher-order assessment questions are often those that ask students to: predict, design, apply, defend, propose, or judge. Analysis of the verbs used in either course student-learning outcomes or course assessments with reference to Bloom's taxonomy can be a useful exercise for instructors who are re-evaluating their approach to teaching.

For further exploration…

1. Allen DE, Tanner KD (2002). Questions about questions. Cell Biol Educ *1*, 63–67.
2. Crowe A, Dirks C, Wenderoth MP (2008). Biology in Bloom: implementing Bloom's taxonomy to enhance student learning in biology. CBE Life Sci Educ *7*, 368.

20. Classroom Assessment Techniques (CATs)

CATs are a suite of strategies instructors can use to integrate low-stakes, formative assessments into their teaching. The term "CAT" is often used to convey the use of clear, regular, purposeful assessment within a course that drives student learning and provides evidence to guide the learning process for instructors and students. With their influential book *Classroom Assessment Techniques*, Angelo and Cross (1993) revolutionized the role of assessment for instructors in higher education. The premise of their work is simple: instructors should use regular, low-stakes assessments both during and outside class time to engage students in learning. Many simple CATs were discussed earlier in the section on active learning; examples include minute papers, clicker questions, concept maps, and think–pair–share discussions, to name a few. Depending on the instructional goals, CATs can employ closed-ended assessment questions, open-ended assessment questions, and questions at a variety of Bloom's taxonomy levels. Importantly, classroom assessment activities can be embedded anywhere in a course: during class, as homework, during discussion sections, as part of online tutorials, or during labs.

For further exploration…

1. Angelo TA, Cross KP (1993). Classroom Assessment Techniques: A Handbook for College Teachers, San Francisco, CA: Jossey-Bass.
2. Dirks C, Wenderoth MP, Withers M (2014). Assessment in the College Science Classroom, New York: Freeman.

21. Grading, 22. Criterion-Referenced Grading, and 23. Norm-Referenced Grading

Grading is defined as the point at which the results of instructor assessment activities become evaluations of students' understanding of the subject. As instructors, grading—in place of learning—can inappropriately appear to be the goal of our teaching efforts. With few exceptions, instructors have to provide a letter grade at the end of the semester for each student. It is a task disliked by many instructors, not only because of the added workload associated with it but also because of the evaluative nature that requires us to make judgments about students' academic performance. However, instructors have choices about how to approach the translation of assessment evidence into grades. In particular, instructors can choose to construct their course's learning environment with either criterion-referenced grading or norm-referenced grading. In criterion-referenced grading, the instructor sets a clear set of expectations for achievement and assumes that students who meet those criteria will receive the corresponding grade. For example, a course that uses criterion-referenced grading would include on the syllabus a list of letter grades associated with percent scores in the course, which do not change based on the class performance. An advantage of criterion-referenced grading is that it provides transparency for students about the grading process, so they can self-evaluate their performance. Additionally, collaboration can be encouraged in a criterion-referenced grading environment.

In contrast, norm-referenced grading presumes that final grades will be distributed based on a normal, bell-shaped curve of performance in which students are essentially competing with one another for the top grades. This type of grading—which has a strong history in undergraduate science courses—has several implicit disadvantages: iterative self-evaluation throughout the course becomes less important, collaboration is subtly discouraged, and competition is likely fostered by the instructor, whether intentional or not. As instructors move toward promoting peer instruction, group work, and collaboration through active learning, criterion-referenced grading becomes much more advantageous than norm-referenced grading in constructing active-learning environments.

For further exploration…

1. Schinske J, Tanner KD (2014). Teaching more by grading less (or differently). CBE Life Sci Educ *13*, 159–166.
2. Huba ME, Freed JE (2000). Learner-centered Assessment on College Campuses: Shifting the Focus from Teaching to Learning, Needham Heights, MA: Allyn and Bacon.

24. Rubrics

Rubrics communicate expectations for student performance on a task and can be one of the most powerful tools in an instructor's toolbox. Rubrics are defined as a set of expectations that illuminate the criteria on which student assignments will be judged. Because they make a set of fixed expectations public, rubrics provide students and instructors with a shared framework to gauge progress and evaluate the work. This is especially important in multifaceted assignments that require critical thinking, content knowledge, and communications skills. Approaches to developing rubrics vary from holistic to reductionist and from comprehensive to simple. A holistic rubric might describe general expectations for the caliber of work, stating only the criteria for excellence in broad strokes. A more detailed rubric offers multiple categories of criteria, with descriptions of work at different levels, ranging from excellent to inadequate. Whatever the approach, rubrics can afford instructors efficiency in grading students' work, by making very clear what caliber of work earns what level of points. However, rubrics are arguably even more important for students as a guide in *crafting* their work assignments, because they are empowered to monitor their own progress against fixed criteria or get feedback from peers and instructors on early drafts of their work.

For further exploration…

1. Allen DE, Tanner KD (2006). Rubrics: tools for making learning goals and evaluation criteria explicit for both teachers and learners. Cell Biol Educ *5*, 197–203.
2. Bean J (2011) Rubrics. In: Engaging Ideas: The Professor's Guide to Integrating Writing, Critical Thinking, and Active Learning in the Classroom, San Francisco, CA: Jossey-Bass, chap. 14.

EQUITY, DIVERSITY, AND INCLUSIVITY: CREATING FAIR AND ACCESSIBLE LEARNING ENVIRONMENTS

The third pillar of scientific teaching encompasses equity, diversity, and inclusivity. As a biology education community, we focus a great deal of time and energy on issues of "what" students should be learning, as well as on the "how" of teaching. Yet the aspect of classroom teaching that seems to be consistently underappreciated is the nature of "whom" we are teaching. Undergraduate students often appear to be treated as monolithic without attention to research on the pervasive influence that an individual's personal history and characteristics, culture, and prior experiences in society and in classrooms all have on the teaching and learning processes in our own classrooms. We provide here brief introductions to commonly encountered terms in biology education that are central to understanding, communicating about, and gaining insight into "whom" we are teaching and the efforts underway across the nation to make biology teaching and learning more fair. In the following sections, we introduce 15 key terms that biologists would likely encounter in their explorations of equity, diversity, and inclusivity in biology education.

25. Equity, 26. Diversity, and 27. Inclusivity

All biology education terms, but perhaps especially these—equity, diversity, inclusivity, and inclusive teaching—can have different meanings for different individuals. The spirit of these terms relates to the goal of having all students in a classroom feel overtly included, allowing them to see themselves and their communities in the biology they are learning and to have multiple ways to access and learn the biological ideas. The term "equity" refers to promoting fairness among diverse individuals in a single setting. As an example, only providing access to learning through listening would be deeply unfair to deaf students, which would seem obvious, but also to students who need time to talk through ideas, which may be less obvious. The term "diversity" refers to the myriad differences among students. It tends to conjure ideas about race when used in the United States, and while racial diversity is one key aspect of diversity, so are a number of other axes along which students may see experiences classrooms in different ways: gender, sexual orientation, first-generation college attending, first-generation U.S. citizen, speaking English as a second language, learning disabilities, and the list goes on and on. As such, "inclusivity" and "inclusive teaching" are terms that are intended to encompass all forms of diversity and all attempts at equity into a single idea of creating classrooms where *all* students feel included.

For further exploration…

1. Tanner KD, Allen DE (2007). Cultural competence in the college biology classroom. CBE Life Sci Educ *6*, 251–258.
2. Handelsman J, Miller S, Pfund C (2006). Scientific Teaching, New York: Freeman.

28. Student-Deficit Model

"Students just aren't motivated." "Nonmajors just aren't interested in biology." While each of these statements may seem innocuous, they reflect a student-deficit model approach to explaining challenges in teaching and learning, in which the underlying assumption is that the root of the problem lies with students. Additionally, these statements ignore possible contributions of other factors, such as the teacher (who is often the speaker), the quality of teaching, the structure of the learning environment, or a host of other sources beside students. Student-deficit model thinking is often criticized as unscientific in that it assigns blame to one locus of a complex environment and with little to no evidence. Shifts away from student-deficit models and toward learning environment–deficit models or teaching-deficit models are thought to be key for reforming undergraduate biology education and diversifying the scientific workforce.

For further exploration…

1. Trujillo G, Tanner KD (2014). Considering the role of affect in learning: monitoring students' self-efficacy, sense of belonging, and science identity. CBE Life Sci Educ *13*, 6–15.
2. Tanner KD, Allen DE (2007). Cultural competence in the college biology classroom. CBE Life Sci Educ *6*, 251–258.

29. Achievement Gap and 30. Instructional Selection

Learning to see inequity in science is critical to anyone who is actively encouraging young people to invest their educations, careers, and lives in the discipline. If the culture of science is grossly inequitable, why should students take the risk of entering this discipline over careers in other arenas? Many scholarly publications from the fields of psychology, science education, and sociology have described inequities in science, proposed theoretical frameworks for understanding them, and explored practical strategies for addressing such inequities (e.g., Tobias, 1990; Seymour and Hewitt, 1997;

Brown, 2004; Johnson, 2007; Tanner, 2007; Chamany *et al.*, 2008), but progress toward eliminating these inequities from our discipline has been slow. By most academic measures, an achievement gap persists from kindergarten through college, defined as a differential between the success of white and Asian students compared with African-American, Latino/a, and Native American students. Some suggest this is due to instructional selection, namely, that traditional, lecture-based learning environments favor students who learn well in that format, while students who prefer other modes are more likely to leave the discipline. Developing an "equity eye"—an ability to analyze the fairness, inequity, and relative participation and success of different types of individuals—causes biologists never to see science classrooms, science conferences, or anything else in their discipline quite the same way ever again.

For further exploration…

1. Tanner KD, Allen DE (2004b). Learning styles and the problem of instructional selection—engaging all students in science courses Cell Biol Educ *3*, 197–201.
2. Tobias S (1990). They're Not Dumb, They're Different: Stalking the Second Tier, Tucson, AZ: Research Corporation.

31. Stereotype Threat

Stereotype threat is a psychological state in which an individual fears that his or her academic performance might confirm an existing stereotype of a cultural, ethnic, gender, or other group with which he or she is identified. This fear, which may be conscious or subconscious, can then lead to profound impairment of that individual's academic performance (Steele and Aronson, 1995; Steele, 1999), with some hypothesizing that this impairment is mediated by cortisol stress responses that may impede working memory (reviewed in Schmader *et al.*, 2008). Stereotype threat is thought to most influence those individuals who care deeply about succeeding within the context in which they experience the threat. Stereotype threat can be induced in a variety of ways in experimental psychology laboratory settings, ranging from explicit threats (e.g., stating that women generally do not perform as well on math tests as men) to implicit threats (e.g., having women take a math test in a room in which men are the majority). Importantly, the influence of stereotype threat is profound. As an example, the test performance of women who had been previously shown to perform in the 90th percentile on a challenging math assessment was decreased by almost 50% in a situation of stereotype threat (Johns, 2005). While stereotype threat has been studied to a lesser extent in situ in undergraduate classrooms, ongoing implicit threat situations likely exist in the sciences, given the low proportions of students of color and women in these classrooms. Additionally, it is hypothesized that some undergraduate science instructors may unintentionally use explicit threat language or examples in science classrooms.

For further exploration…

1. Steele C (2010). Whistling Vivaldi: And Other Clues How Stereotypes Affect Us, New York: Norton.
2. Steele CM, Aronson J (1995). Stereotype threat and the intellectual test performance of African Americans. J Personality Soc Psychol *69*, 797–811.

32. Retention and 33. Persistence

Retention refers to efforts by institutions to keep diverse populations of students engaged and enrolled in a particular discipline. Similarly, persistence is defined as students remaining in that major from year to year, through graduation. In the case of biology education, as with many historically white-dominated majors, the goal of retention and persistence is to increase the diversity of this graduating population. Research suggests that undergraduate students are more likely to leave the sciences than other fields, with estimates of ~60% of undergraduate biology majors leaving the discipline during their college years (Seymour and Hewitt, 1997). Intriguingly, students who left their majors in the sciences reported reasons that were similar to complaints of those students who stayed. Top reported reasons for leaving undergraduate science majors included poor faculty pedagogy, an overwhelming amount of information, loss of interest in the discipline, and a competitive classroom culture (Seymour and Hewitt, 1997). Many retention efforts in college and universities have focused on supporting students in navigating these reported challenges, in an effort to foster persistence within a science major until graduation without leaving. Intriguingly, aspirations to increase retention appear to focus less on addressing the reasons for leaving, which might be best remedied by extensive science faculty professional development in effective science teaching.

For further exploration…

1. Seymour E, Hewitt NM (1997). Talking about Leaving: Why Undergraduates Leave the Sciences, Boulder, CO: Westview.
2. Tobias S (1990). They're Not Dumb, They're Different: Stalking the Second Tier, Tucson, AZ: Research Corporation.

34. Underrepresented Minority (URM), 35. Students of Color, and 36. First-Generation Students

There is confusion and chronic misuse of the following terms in conversations about diversifying the sciences, usually by well-intentioned individuals: URM, disadvantaged, poor, and academically underperforming. The term "underrepresented minority," or URM, specifically designates a student as being a member of a group that, historically, has been proportionately underrepresented in U.S. academic science. URM populations as defined by the National Institutes of Health include African-American, Latino/a, and Native American students. Most importantly, just because a student is an URM does not imply he or she is "disadvantaged," "poor," or "underperforming." In fact, the inattentive interchanging of URM with "underperforming" and "disadvantaged" serves to propagate unfounded stereotypes about students of color in the sciences, stereotypes that can artificially reduce their academic performance and success in the sciences (see *31. Stereotype Threat*). The term "student of color" is a more inclusive term than URM, in that it usually refers to any student from a nonwhite background, including students from the Middle East and Asian and South Asian countries such as the Philippines, China, India, and Indonesia. Finally, the term "first generation" is often a shortened version of "first-generation, college-attending student," namely, a student whose parents or other relatives have not had the privilege of access to higher education. Alternatively, the term "first generation" may refer to a student's citizenship status in the United States, with a first-generation student being the first in his or her family to be born in the United States.

For further exploration…

1. Hurtado S, Carter D (1997). Effects of college transition and perceptions of the campus racial climate on Latino college students' sense of belonging. Sociol Educ *70*, 324–345.
2. Ladson-Billings G (1995). But that's just good teaching! The case for culturally relevant pedagogy. Theory Pract *34*, 159–165.

37. Self-Efficacy

While not a term scientists often encounter, self-efficacy is likely a familiar concept: namely, the perceptions a person holds about his or her ability (or lack thereof) to succeed and achieve. A commonly heard example is a variation on: "I'm just bad at science and math." Self-efficacy, no doubt, results from a host of influences, including personal background, personality, immediate social interactions, and societal biases and attitudes. However, undergraduate science course instructors have enormous power to influence students' self-efficacy by their attitudes toward students and comments they make about students and their work in courses. It seems an obvious statement that, if we do not believe in students and promote their positive self-efficacy in science, we risk that those students will not believe in themselves. And if they do not believe in themselves, they have little chance of persisting through the challenges inherent in biology learning.

For further exploration…

1. Trujillo G, Tanner KD (2014). Considering the role of affect in learning: monitoring students' self-efficacy, sense of belonging, and science identity. CBE Life Sci Educ *13*, 6–15.
2. Bandura A (1997). Self-Efficacy: The Exercise of Control, New York: Freeman.

38. Unconscious or Implicit Bias

While scientists may like to believe that science is objective and unbiased, researchers in cognitive and social psychology have extensively documented that humans across a variety of professions, including our own, are influenced daily by unconscious bias, which is manifested by treating individuals differently based on their personal characteristics. Unconscious bias may occur when forming opinions of how intelligent students are, how hard they are working, or whether they deserve the benefit of the doubt when grading, for example. Recent studies in university-level science courses suggest that unconscious bias against female students is just as common among female faculty members as male faculty members, suggesting that unconscious bias is a product of societal influences and not strongly correlated with one's own personal characteristics (Moss-Racusin *et al*., 2012). Importantly, raising one's own awareness of unconscious bias and being vigilant in questioning one's own biases is currently the most immediate action instructors can take to decrease bias in their teaching. For example, tracking (mentally or on paper) the personal characteristics of students (e.g., gender) called on to speak during class discussions can alert an instructor to unconscious tendencies to call preferentially on students of one gender. Additional strategies to decrease unconscious bias include blinding oneself to student identity whenever possible, especially when grading exams, which is easily done by having students write their names on the back of exams.

For further exploration…

1. Moss-Racusin CA, Dovidio JF, Brescoli VL, Graham MJ, Handelsman J (2012). Science faculty's subtle gender biases favor male students. Proc Natl Acad Sci USA *109*,16474–16479.
2. Tanner KD (2009a). Learning to see equity in science. CBE Life Sci Educ *8*, 265–270.

39. Equitable Teaching Strategies

Designing learning environments that attend to individual students and their interactions with one another may seem an impossible task in a course of 20 students, much less a course of more than 700. However, there are a host of simple teaching strategies, rooted in research on teaching and learning, that can support biology instructors in making classrooms fair and inclusive. These teaching strategies are sometimes referred to as "equitable teaching strategies," wherein striving for classroom equity is about teaching *all* the students in your classroom not just those who are already engaged, already participating, and perhaps already know the biology being taught. Equity, then, is about striving to *structure* biology classroom environments that maximize fairness, environments in which *all* students have opportunities to verbally participate, *all* students can see their personal connections to biology, *all* students have the time to think, *all* students can pose ideas and construct their knowledge of biology, and *all* students are explicitly welcomed into the intellectual discussion of biology. Without attention to the structure of classroom interactions, what can often ensue is a biology lesson that can be accessed by only a small subset of students in a classroom. Examples of equitable teaching strategies include simple ways instructors can actively structure classroom interactions such as: 1) think–pair–share, 2) wait time, 3) multiple hands, multiple voices, 4) allowing students time to write, as well as more involved strategies such as 5) integrating culturally diverse examples, 6) using varied active-learning strategies, 7) being explicit about promoting access and equity, and 8) establishing classroom community and norms (Tanner, 2013).

For further exploration…

1. Tanner KD (2013). Structure matters: twenty-one teaching strategies to promote student engagement and cultivate classroom equity. CBE Life Sci Educ *12*, 322–331.

2. Chamany K, Allen DE, Tanner KD (2008). Making biology learning relevant to students: integrating people, history, and context into college biology teaching. CBE Life Sci Educ *7*, 267–278.

MOVING TO PRACTICE: INSTRUCTIONAL DESIGN, LEARNING, AND TECHNOLOGIES

While the ideas of scientific teaching—active learning, assessment, and inclusivity—may intrigue many instructors, translating these ideas into classroom teaching practices can prove challenging for even experienced instructors. In particular, incorporating scientific teaching into practice requires instructors to refocus their efforts on student learning rather than teaching. To enact this philosophical shift at the practical level, instructors can use a variety of tools to make small changes to their teaching that bring together active learning, assessment, and equity considerations, described in the previous sections. We introduce here 11 key terms that relate to tools and strategies to support biologists in translating scientific teaching into practice.

40. Backward Design

In their influential book *Understanding by Design* Wiggins and McTighe (1998) rejected the traditional approach to course design, which generally begins with writing a syllabus that follows the order of the textbook and, later, writing exams after having delivered a series of lectures. Instead, they proposed that instructors could best support student learning by approaching course design "backward," namely, by determining what students should be able to do at the end of a course, designing the assessments by which this would be measured, and then working backward to design learning experiences to get them there. Wiggins and McTighe's approach was termed "backward design," because the instructor begins planning with the end goals of the course, namely, student learning outcomes and the assessments by which they will be evaluated, *then* designs the learning experiences. The approach is simple. First, instructors determine what they aspire for students to be able to understand and do with that understanding by the end of a course, establishing clearly these student learning outcomes. Then, instructors engage in designing assessment tools that can be used to gauge student understanding early in the course and to evaluate the extent to which learning outcomes are achieved. Only at this point would instructors begin to craft learning experiences—including readings, homework problems, projects, and/or in-class activities—that would support students in their learning and in achieving the instructors' projected student learning outcomes. While backward design—much like the scientific method—is in theory linear, it is in practice an iterative, nuanced process that requires constant reevaluation of the alignment among learning outcomes, assessments, and learning activities.

For further exploration…

1. Allen DE, Tanner KD (2007). Putting the horse back in front of the cart: using visions and decisions about high-quality learning experiences to drive course design. CBE Life Sci Educ *6*, 85–89.
2. Wiggins GP, McTighe J (1998). Understanding by Design, Alexandria, VA: Association for Supervision and Curriculum Development.

41. Learning Theory and 42. The 5E Model

Learning theory proposes that students should have ample opportunities to interact with the material they are learning. Many researchers have proposed variations on learning models, but most share a few common elements, captured well by Ambrose *et al*. (2010). First, students' prior knowledge can positively or negatively influence learning. Second, how students organize the knowledge they are acquiring influences both how they learn and how they will be able to apply what they know. Third, students' motivation determines, directs, and sustains what they do to learn. Fourth, for students to develop mastery, they must acquire skills, practice them, and know when to apply them. Fifth, goal-directed practice, accompanied by targeted feedback, enhances the quality of learning. Sixth, students' own levels of development interact with the social, emotional, and intellectual climate of the classroom to influence the learning process. Seventh, to become self-directed learners, students must learn to monitor and adjust their approaches to learning (see *43. Metacognition*). While these tenets of learning theory seem like important considerations, instructors often struggle with how to account for these ideas in planning learning activities for students.

The 5E model (Bybee *et al*., 2006), translates what is known about how humans learn from research in various disciplines—cognitive science, psychology, and science education—into a tool that guides instructors in planning effective learning experiences for students. The five "E"s—engage, explore, explain, elaborate, and evaluate—capture the optimal order in which students navigate learning. First, students must be interested and engaged in the concepts at hand. Then, learning is best facilitated when students have opportunities to explore their prior knowledge of the topic. At that point, instructors and students are likely ready to engage in coexamination and coexplanation of the ideas under study. At this point, students need opportunities for deliberate practice through elaboration—application of the concepts learned to new contexts or problems. And finally, upon completion of these components of the cycle, students and instructors (together) evaluate what students have learned. The 5E model may be a helpful tool instructors can use to analyze their current approaches to teaching, identifying which aspects ("E"s) of the learning cycle may be missing from their instruction and which pieces of their current instruction can simply be reordered to provide students with more opportunities for engagement and exploration before explanations are offered.

For further exploration…

1. Tanner KD (2010). Order matters: using the 5E model to align teaching with how people learn. CBE Life Sci Educ *9*, 159–164.
2. Ambrose S, Bridges MW, DiPietro M, Lovett MC, Norman MK (2010). How Learning Works: Seven Research-based Principles for Smart Teaching, San Francisco, CA: Jossey-Bass.

43. Metacognition

To become self-directed learners, students must learn to develop a "meta-level" awareness of their learning through which they can monitor and adjust their approaches to learning; this is called "metacognition." During this process, students self-evaluate what they are and are not understanding in a course and determine what actions might set them on a better path to achieving the learning outcomes. Metacognition can be approached in a variety of ways. For example, instructors can use preassessments to encourage students to examine their current thinking about biological concepts before considering any new instruction on the concept at hand; students are then empowered to focus on what they need to learn and to develop strategies to do so. Additionally, instructors can ask students outright to identify their confusions through in-class minute papers or homework assignments; again, raising awareness of where the students need to learn more helps prioritize what and how to study. Perhaps most importantly, metacognition can be encouraged in biology classrooms by giving students the license to be incorrect and share their nascent thinking, which may be scientifically inaccurate, as part of the learning process. Teaching students to use metacognition to understand how they are thinking about biology provides an important step on the path to thinking like a biologist.

For further exploration…

1. Tanner KD (2012). Promoting student metacognition. CBE Life Sci Educ *11*, 113–120.
2. Pintrich P (2002). The role of metacognitive knowledge in learning, teaching, and assessing. Theory Pract *41*, 219–226.

44. Syllabus

The syllabus is a document that offers the first opportunity for faculty members to communicate with their students about the course and provides a guiding framework that sets the tone and expectations for the semester. The conventional syllabus is composed of a calendar that relays the sequential order of topics to be covered during the semester, along with other information about the course meeting times and contact information. A more detailed, arguably learner-focused syllabus might also describe what learning outcomes students should achieve by the end of the course, outline how learning will be assessed, or delineate the responsibilities of both instructor and students for achieving the course goals. In the syllabus, instructors have the opportunity to set the tone of the learning environment they hope to cultivate, minimize student resistance, and focus students on strategies for learning.

For further exploration…

1. Bain K (2004). What the Best College Teachers Do, Cambridge, MA: Harvard University Press.
2. Filene P (2005). The Joy of Teaching: A Practical Guide for New College Instructors, Chapel Hill: University of North Carolina Press.

45. Lesson Plans

Lesson plans are outcome-oriented organizers that provide the day-by-day details and supporting materials for an instructional plan. For some instructors who currently keep few records related to their teaching beyond lecture slides and notes, lesson plans are a first step toward more purposefully planned class time. How? A well-crafted lesson plan allows the course outcomes to manifest as real actions by linking outcomes to activities (what the instructor and students are both doing), connecting them with the assessments (what is being gauged or graded at any point), and noting the actual times these things should happen (in and out of class). They include detailed instructor notes that explain how to launch and wrap up student activities, show how to transition to a technology-enabled portion of the class period, predict what students will say (e.g., questions students might ask or brainstorm comments they might make, plus notes about how to deal with them), aggregate any notes and PowerPoint slides, provide any student handouts or materials (e.g., clickers, note cards, etc.), and collate any other preparatory materials the instructors or students might need. In addition, they can serve as the first step toward collecting evidence about the effectiveness of the instruction, enabling iterative improvement in future offerings of the course.

For further exploration…

1. Handelsman J, Miller S, Pfund C (2006). Scientific Teaching, New York: Freeman.
2. Roth D (2007). Understanding by design: a framework for effecting curricular development and assessment. CBE Life Sci Educ *6*, 95–97.

46. Learning Technologies, 47. Blended Learning, and 48. Universal Design

Learning technologies encompass all the instructional technologies that can be integrated into college courses across a spectrum of formats, ranging from fully face-to-face meetings to completely online environments. Most courses naturally fall somewhere in between, in a space dubbed "blended learning," in which some aspects of teaching and learning occur face-to-face and others online. This term captures the integrated spirit and structure of these courses, which "are instructor-designed and supervised environments that use face-to-face and technology-mediated channels to enhance interactive, engaging learning experiences and to improve student learning outcomes" (https://blendedtoolkit.wisc.edu). When integrating technology, it is critical to consider not just the learning outcomes and the teaching approaches used to achieve these outcomes, but also the managerial, technical, and social aspects of the instruction. Finally, technology elevates issues related to accessibility. Principles of universal design ensure that online and computer-aided elements are accessible to all audiences by accounting for particular disabilities, such as visual or auditory impairments, or varied computer platforms.

For further exploration…

1. Twigg C (2003). Improving learning and reducing costs: new models for online learning. EDUCAUSE Rev *September/October*, 28–38.
2. Gaffney JDH, Richards E, Kustusch MB, Ding L, Beichner RJ (2008). Scaling up education reform. J Coll Sci Teach *May/June*, 18–23.

49. Scientific Teaching and 50. Nature of Science in the Classroom

The crux of scientific teaching is twofold: the instructor approaches teaching with the same guiding practices and philosophies of scientific research, while in parallel affording opportunities for students to experience the iterative process of thinking and discovery that is characteristic of science. Instructor attention to the tenets of scientific teaching—active learning; assessment; and equity, diversity, and inclusion—are the means by which instructors can construct effective learning environments for students. From the instructor perspective, it is an intentional approach to teaching that involves questioning, evidence, and innovation. In the same spirit, students learn how to engage in asking questions, using evidence to answer those questions, and to be creative in solving real-world problems; this is the nature of science. And the more students and instructors integrate scientific practices and habits of mind into everything about the teaching and learning of college biology, the more authentic each classroom experience will be, and the more each student will experience being a scientist. In this paper, we have unpacked some of the key components of scientific teaching that were originally explored in the book *Scientific Teaching* (Handelsman *et al.*, 2006) and highlighted the key terms and practices we believe are most critical for the new or future instructor.

For further exploration…

1. Handelsman J, Ebert-May D, Beichner R, Bruns P, Chang A, DeHaan R, Gentile J, Lauffer S, Stewart J, Tilghman SM, Wood WB (2004). Scientific teaching. Science *304*, 521–522.
2. Handelsman J, Miller S, Pfund C (2006). Scientific Teaching, New York: Freeman.

IN CONCLUSION

We have attempted here to offer readers at various stages of their careers a portal into the language of biology education. Whether you are a graduate student or postdoctoral fellow, a recently hired faculty member teaching for the first time or a seasoned classroom veteran seeking new ideas and research literatures in biology education, we encourage you to continue your explorations of biology education far beyond these introductory paragraphs. It is an incredibly exciting time to be engaged in biology education efforts, as the disciplines of neurobiology, science education, psychology, and cognitive science increasingly overlap in the focus of their research. No doubt, just like the basic biological mechanisms that we study, these biology education ideas will change over time with new biology education research and emerging evidence, and we hope that you will follow these developments with as much enthusiasm as you follow new discoveries in other fields.

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