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Structure Matters: Twenty-One Teaching Strategies to Promote Student Engagement and Cultivate Classroom Equity

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Abstract

A host of simple teaching strategies—referred to as "equitable teaching strategies" and rooted in research on learning—can support biology instructors in striving for classroom equity and in teaching *all* their students, not just those who are already engaged, already participating, and perhaps already know the biology being taught.

INTRODUCTION

As a biology education community, we focus a great deal of time and energy on issues of "what" students should be learning in the modern age of biology and then probing the extent to which students are learning these things. Additionally, there has been increased focus over time on the "how" of teaching, with attention to questioning the efficacy of traditional lecture methods and exploring new teaching techniques to support students in more effectively learning the "what" of biology. However, 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 interchangeable entities without acknowledgment of the central role of the individual students, their learning histories, and their personal characteristics in the student-centered nature of "how" we aspire to teach. Most innovative approaches to biology teaching that are at the core of national policy documents and resources are rooted in a constructivist framework (e.g., Posner *et al.*, 1982; Handelsman *et al.*, 2004; Labov *et al.*, 2010; American Association for the Advancement of Science [AAAS], 2011; College Board, 2013). In constructivism, teachers can structure classroom environments with the intention of maximizing student learning, but learning is the work of students (Posner *et al.*, 1982; Bransford *et al.*, 2000). As such, each student's prior experience and attitude and motivation toward the material being learned, confidence in his or her ability to learn, and relative participation in the learning environment are all thought to be key variables in promoting learning of new ideas, biological or not. Finally, bringing together individual students in classrooms produces group interactions that can either support or impede learning for different individuals.

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 paying attention to whom they are trying to help learn. These teaching strategies are sometimes referred to as "equitable teaching strategies," whereby 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, wherein *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 wonderfully designed biology lesson that can be accessed by only a small subset of students in a classroom.

So what specific teaching strategies might we instructors, as architects of the learning environment in our classrooms, use to structure the classroom learning environment? Below are 21 simple teaching strategies that biology instructors can use to promote student engagement and cultivate classroom equity. To provide a framework for how these teaching strategies might be most useful to instructors, I have organized them into five sections, representing overarching goals instructors may have for their classrooms, including:

- Giving students opportunities to think and talk about biology
- Encouraging, demanding, and actively managing the participation of *all* students
- Building an inclusive and fair classroom community for *all* students
- Monitoring behavior to cultivate divergent biological thinking
- Teaching *all* of the students in your biology classroom

For each of these goals, there is a brief consideration of why the goal is important for student learning, which is followed by descriptions of several simple strategies for structuring instructor–student and student–student interactions to strive for this goal. No doubt, there are likely dozens of additional strategies that could be added to this list. In addition, many of the strategies affiliated with one equitable teaching goal are also easily used in the service of one or more of the other goals. The intention of presenting these 21 strategies in this framework is solely to provide *all* biology instructors access to immediate and tractable teaching strategies for promoting access and equity for *all* students in their biology classrooms.

These equitable teaching strategies can be read and explored in any order. Readers are encouraged to use Table 1 to self-assess which of these strategies they may already use, which they are most interested in reading more about, and which they may want to try in their own classrooms. Self-assessment responses to Table 1 can guide which of the sections below you may be most interested in reading first.

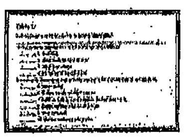

Table 1.
Self-assessment of equitable teaching strategies[a]

GIVING STUDENTS OPPORTUNITIES TO THINK AND TALK ABOUT BIOLOGY

Human learning is a biological phenomenon of the brain. Synapses need time to fire, and relevant circuits in the brain need time to be recruited. Yet the structure of class time with students does not usually attend to giving students time to think and talk about biology. As experts with thousands of hours of thinking about biology, we as biologists no doubt think quite quickly about the topics we are attempting to teach students. And we as instructors can be misled that all students have had ample time to think by those few students in our courses who have more background in the concepts under discussion and raise their hands to share almost immediately. However, those students in our courses who are more biologically naïve may need more time to think and talk about the biological concepts under discussion. Below are four simple teaching strategies grounded in research to structure classroom time for students to think and talk about biology.

1. Wait Time

Perhaps the simplest teaching strategy to increase time for student thinking and to expand the number of students participating verbally in a biology classroom is to lengthen one's "wait time" after posing a question to your class (Rowe, 1969; Tobin, 1987 ▸). Mary Budd Rowe's groundbreaking papers introducing the concept of wait time have influenced educational practice since their publication more than 40 years ago (Rowe, 1969, 1974, 1978, 1987; Tanner and Allen, 2002). Rowe and colleagues documented in the precollege setting that instructors on average waited only ~1.5 s after asking a question before taking a student response, answering the question themselves, or posing a follow-up question. With the seemingly modest extension of the "wait time" after a question to ~3–5 s, Rowe and colleagues showed dramatic effects: substantially more students willing to volunteer answers, fewer students unwilling to share when called on, and increases in the length and complexity of the responses that students gave in response to the question (Rowe, 1974, 1978; Allen and Tanner, 2002 ▸). Thinking biologically about increasing wait time to promote student engagement and participation, it seems likely that this increase in time allows critical neural processing time for students, and perhaps also allows more introverted students time to rally the courage to volunteer an answer. Practically, extending wait time can be very challenging for instructors. Actively mentally counting the following —"one thousand one … one thousand two … one thousand three … one thousand four … one thousand five"—before acknowledging potential student respondents is one simple way to track the amount of time that has transpired after asking a question.

2. Allow Students Time to Write

Practicing wait time may still not give enough time for some students to gather a thought and or screw up the confidence to share that thought. Many students may need more scaffolding—more instruction and guidance—about how to use the time they have been given to think. One simple way to scaffold wait time is to explicitly require students to write out one idea, two ideas, three ideas that would capture their initial thoughts on how to answer the question posed. This act of writing itself may even lead students to discover points of confusion or key insights. In addition, if collected, this writing can hold students accountable in thinking and recording their ideas. To set the stage for doing these simple quick writes or minute papers throughout the semester, instructors can require on the syllabus that students purchase a packet of index cards (usually no more than a $1 cost) and bring a few cards to each class session for the purpose of these writing opportunities. Instructors need not collect all of these writings, though it may be quite informative to do so, and certainly instructors need not grade any (much less every) card that students produce. If these quick writes are graded, it can be only for participation points or more elaborately to provide conceptual feedback (Schinske, 2011 ▸). Giving students time to write is one way that instructors can structure the learning environment to maximize the number of students who have access (in this case enough time) to participate in thinking about biology.

3. Think–Pair–Share

The oft written about think–pair–share strategy is perhaps the simplest way for instructors coming from a traditional lecture approach to give *all* students in a classroom opportunities to think about and talk about biology (Lyman, 1981 ▸; Chi *et al.*, 1994 ▸; Allen and Tanner, 2002 ▸; Smith *et al.*, 2009 ▸; Tanner, 2009 ▸). The mechanics of a think–pair–share generally involve giving all students a minute or so to think (or usually write) about their ideas on a biological question. Then, students are charged to turn and talk with a neighboring student, compare ideas, and identify points of agreement and misalignment. These pair discussions may or may not be followed by a whole-group conversation in which individual students are asked to share the results of their pair discussion aloud with the whole class. Importantly, the instructor's role in facilitating a think–pair–share activity is to be explicit that students need not agree and also to convey that practicing talking about biology is an essential part of learning about biology. Integrating one or more think–pair–share opportunities during a class session has the potential to cultivate classroom equity in multiple ways: providing individual students time to verbalize their thoughts about biological concepts; promoting comparison of ideas among classmates; transforming the nature of the classroom environment to be more participatory; and promoting a collaborative, rather than competitive, culture in undergraduate science classes. Methodologically, a think–pair–share activity need not take more than a few minutes of class time, yet may allow students the neural processing time needed before being ready to take on new information offered by an instructor. It is also during these pair discussions that students may discover new confusions or points of disagreement about concepts with fellow students, which can drive questions to be asked of the instructor.

4. Do Not Try to Do Too Much

Finally, no instructors would likely express the sentiment: "I try to do so much in my class sessions that they go by quickly and students are unclear about what the goals for the class were." However, evidence from a variety of research studies suggests that this may be the dominant experience for many students in undergraduate science courses (Tobias, 1990 ▸; Seymour and Hewitt, 1997). While "not doing too much" is a challenging task for most of us, one particular strategy that can reduce the amount of material considered during class time is to structure more active learning by students outside class time, in particular in the form of homework that goes beyond textbook readings. Examples include case study assignments that charge students to independently explore and find evidence about an upcoming conceptual idea before arriving in class. As experts in our biological fields, it is tempting to continually expand what we deem critical and nonnegotiable in terms of what students need to accomplish during class time. However, there are clear and present trade-offs between continually expanding our aspirations for in-class time and structuring a classroom learning environment that promotes student engagement and provides access to thinking and talking about biology for all students. One strategy for prioritizing how to spend precious class time is to decide on which biological ideas in a course are most difficult to learn, are rooted in common misconceptions, and/or represent fundamental biological principles (National Research Council, 1999 ▸; AAAS, 2011 ▸; Coley and Tanner, 2012 ▸).

ENCOURAGING, DEMANDING, AND ACTIVELY MANAGING THE PARTICIPATION OF ALL STUDENTS

If learning requires that students construct ideas for themselves, then demanding the active participation of every single student in a class is essential to learning. Currently, though, many undergraduate students in biology classrooms can navigate an entire term without speaking aloud in a course. They sit in the back of our large classrooms, and they attempt to appear to be busily writing when a question is asked in a small class. Being called upon to answer a question or share an idea can be deeply uncomfortable to many students, and we as instructors may not be doing enough to build students' confidence to share. While few instructors would find this lack of active, verbal participation in science acceptable for emerging scientists such as graduate students or practicing scientists themselves, we somehow allow this for undergraduate students. The participation of a only few students in our classrooms on a regular basis, often from the front rows, distracts us from the fact that usually the vast majority of students are not participating in the conversation of biology. To encourage, and in fact demand, the participation of all students in a biology classroom, you can use the following six strategies with little to no preparation or use of class time.

5. Hand Raising

Actively enforcing the use of hand raising and turn taking in a classroom is likely to provide greater access to more students than an open, unregulated discussion. Novice instructors, sometimes awash in silence and desperate for any student participation, can allow the classroom to become an open forum. Some would say this is much like the culture of science in settings such as lab meetings and seminars. However, the undergraduates in our courses are novices, not only to the concepts we are sharing but also to the culture of science itself. As such, providing structure through something as simple as hand raising can establish a culture that the instructor expects all students to be participating. With hand raising, the instructor can also be explicit about asking for "hands from those of us who haven't had a chance yet to share" and strive to cultivate a classroom conversation that goes beyond a few students in the front row.

6. Multiple Hands, Multiple Voices

After asking a question, some instructors call on just a single student to answer. However, this is problematic in many ways. The same students can often end up sharing repeatedly during a class, as well as from class session to class session. In addition, if the goal is to better understand how students are thinking, having a single student share gives a very narrow and highly skewed picture of what a classroom full of students may be thinking. One simple strategy for broadening participation and increasing the breadth of ideas flowing from students to instructors is to generally ask for multiple hands and multiple voices to respond to any question posed during class time (Allen and Tanner, 2002). Instructors can set the stage for this by asserting, "I'm going to pose a question, and I'd like to see at least three hands of colleagues here who would share their ideas. I won't hear from anyone until I've got those three volunteers." Additionally, this particular use of hand raising allows instructors to selectively call on those students who may generally participate less frequently or who may have never previously shared aloud in class. Importantly, instructors really must always wait for the number of hands that they have called for to share. Hearing from fewer than the number of volunteers called for can entrain students in a classroom to know that they simply have to outwait the instructor. Finally, if the number of requested hands have not been volunteered, the instructor can charge students to talk in pairs to rehearse what they could share if called upon to do so.

7. Random Calling Using Popsicle Sticks/Index Cards

Raising hands allows for the instructor to structure and choose which students are participating verbally in a class, but what if no one is raising a hand or the same students continually raise their hands? Establishing the culture in a classroom that any student can be called on at any time is another option for promoting student engagement and participation. How this is done can be critical. If the spirit of calling on students feels like a penalty, it may do more harm than good. However, if the instructor is explicit that all students in the course have great ideas and perspectives to share, then random calling on students in courses that range in size from 10 to 700 can be a useful strategy for broadening student participation. Practically, there are a variety of ways to call randomly on students. In smaller-sized courses, having a cup with popsicle sticks, each with the name of a student on it, can make the process transparent for students, as the instructor can clearly hold up the cup, draw three names, read the names, and begin the sharing. This can minimize suspicions that the instructor is preferentially calling on certain students. For larger course class sizes, instructors can collect an index card with personal information from each student on the first day. The cards serve two purposes: 1) to enable instructors to get to know students and to assist with learning students' names, and 2) to provide a card set that can be used each class and cycled through over the semester to randomly call on different students to share (Tanner, 2011).

8. Assign Reporters for Small Groups

Promoting student engagement and classroom equity involves making opportunities for students to speak who might not naturally do so on their own. If the decision about who is to share aloud in a class discussion is left entirely to student negotiation, it is no surprise that likely the most extroverted and gregarious students will repeatedly and naturally jump at all opportunities to share. However, this sets up an inequitable classroom environment in which students who are unlikely to volunteer have no opportunities to practice sharing their scientific ideas aloud. Assigning a "reporter"—an individual who will report back on their small-group discussion—is a simple strategy to provide access to verbal participation for students who would not otherwise volunteer. The assignment of reporters need not be complex. It can be random and publicly verifiable, such as assigning that the reporter will be the person wearing the darkest shirt. In smaller classes, one can use simple tools to assign a reporter, such as colored clips on individual student name tents or colored index cards handed to students as they enter the class. It can also be nonrandom and intended to draw out a particular population. For example, assigning the group reporter to be the person with the longest hair will often, not always, result in a female being the reporter for a group. Or instructors can choose to hand out the colored clips/cards specifically to students who are less likely to share their ideas in class. Early on, it may be useful to assign based on a visible characteristic, so the instructor can verify that those students reporting are indeed those who were assigned to report. After the culture of assigned reporters is established, and everyone is following the rules, assignments can become less verifiable and prompt more personal sharing, such as the reporter is the person whose birthday is closest. Whatever the method, assigning reporters is a simple strategy for promoting classroom fairness and access to sharing ideas for more than just the most extroverted students.

9. Whip (Around)

Actively managing the participation of all students in smaller courses is sometimes well supported by the occasional use of what is termed a "whip around" or more simply just a "whip." In using a whip, the instructor conveys that hearing an idea from every student in the classroom is an important part of the learning process. Whips can be especially useful toward the beginning of a course term as a mechanism for giving each student practice in exercising his or her voice among the entire group, which for many students is not a familiar experience. The mechanics of the whip are that the instructor poses a question to which each individual student will respond, with each response usually being <30 s in length. On the first day of class, this could be something as simple as asking students what their favorite memory of learning biology has been. As the course progresses, the question that is the focus of the whip can become more conceptual, but always needs to be such that there are a variety of possible responses. Whips can be follow-ups to homework assignments wherein students share a way in which they have identified a personal connection to course material, a confusion they have identified, or an example of how the material under study has recently appeared in the popular press. During a whip, students who may wish to share an idea similar to a colleague who has previously shared are actively encouraged to share that same idea, but in their own words, which may be helpful to the understanding of fellow students or reveal that the ideas are not actually that similar after all. Importantly, the whip is a teaching strategy that is not feasible in large class sizes, as the premise of the strategy is that every student in the class will respond. As such, this strategy is unwieldy in class sizes greater than ~30, unless there is a subgroup structure at play in the classroom with students already functioning regularly in smaller groups. Possible ways to implement a whip in a large classroom could be to call on all students in a particular row or in a particular subgroup structure particular to the course.

10. Monitor Student Participation

Many instructors are familiar with collecting classroom evidence to monitor students' thinking, using clicker questions, minute papers, and a variety of other assessment strategies. Less discussed is the importance of monitoring students' participation in a classroom on a regular basis. It is not unusual to have a subset of students who are enthusiastic in their participation, sometimes to the point that the classroom dialogue becomes dominated by a few students in a room filled with 20, 40, 80, 160, or upward of 300 students. To structure the classroom dialogue in such a way as to encourage, demand, and actively manage the participation of *all* students, instructors can do a variety of things. During each class session, instructors can keep a running list—in smaller classes mentally and in larger classes on a piece of paper—of those students who have contributed to the discussion that day, such as by answering or asking a question. When the same students attempt to volunteer for the second, third, or subsequent times, instructors can explicitly invite participation from other students, using language such as "I know that there are lots of good ideas on this in here, and I'd like to hear from some members of our community who I haven't heard from yet today." At this juncture, wait time is key, as it will likely take time for those students who have not yet participated to gather the courage to join the conversation. If there are still no volunteers after the instructor practices wait time, it may be time to insert a pair discussion, using language such as "We cannot go on until we hear ideas from more members of our scientific community. So, take one minute to check in with a neighbor and gather your thoughts about what you would say to a scientific colleague who had asked you the same question that I'm asking in class right now." At this point it is essential not to resort to the usual student volunteers and not to simply go on with class, because students will learn from that behavior by the instructor that participation of *all* students will not be demanded.

BUILDING AN INCLUSIVE AND FAIR CLASSROOM COMMUNITY FOR *ALL* STUDENTS

Many studies have documented that students from a variety of backgrounds in undergraduate science courses experience feelings of exclusion, competitiveness, and alienation (Tobias, 1990 ▸; Seymour and Hewitt, 1997 ▸; Johnson, 2007 ▸). Research evidence over the past two decades has mounted, supporting the assertion that feelings of exclusion—whether conscious, unconscious, or subconscious —have significant influences on student learning and working memory, as well as the ability to perform in academic situations, even when achievement in those academic arenas has been documented previously (e.g., Steele and Aronson, 1995; ▸ Steele, 1999 ▸). Additionally, our own behaviors as scientists are influenced by unconscious bias in our professional work (Moss-Racusin *et al.*, 2012 ▸). However, there is also research evidence that relatively subtle interventions and efforts in classrooms may be effective at blunting feelings of exclusion and promoting student learning (Cohen *et al.*, 2006 ▸; Miyake *et al.*, 2010 ▸; Haak *et al.*, 2011 ▸; Walton *et al.*, 2013 ▸). The following five strategies may assist biology instructors in working toward an inclusive, fair, and equitable classroom community for *all* of their students.

11. Learn or Have Access to Students' Names

For cultivating a welcoming, inclusive, and equitable classroom environment, one of the simplest strategies an instructor can use is to structure ways to get to know and call students by their names. Some instructors may plead an inability to remember names; however, there are many simple ways to scaffold the use of individual student names in a classroom without memorizing all of them. Having students submit index cards with their names and personal information, as described above, is an easy first step to learning names. Additionally, requiring students to purchase and always bring to class a manila file folder with their first names written on both sides in large block letters is another simple way to begin to make students' names public, both for the instructor and for other students. Instructors who use such folders request that students raise this folder above themselves when asking or answering a question in class, so the instructor can call them by name. More advanced would be for the instructor to personally make the student name tents, preparing perhaps a colorful piece of heavy card stock folded in half, then writing each student's name in large block letters on each side. The simple act of making the name tags—which is feasible in class sizes of up to 100 students—may aid an instructor in beginning the process of learning students' names. Regardless of who makes them, these name tents can be tools for a variety of classroom purposes: to call on students by name during class discussions, to encourage students to know one another and form study groups, and to verify names and faces when collecting exams on exam days. In smaller classes, name tents can be used more extensively, for example, by collecting them at the end of class and sorting them to identify members of small groups for work in the next class session. In fact, the attempt to get to know students' names, and the message it sends about the importance of students in the course, may be more important than actually being able to call students by name each time you see them.

12. Integrate Culturally Diverse and Relevant Examples

Part of building an inclusive biology learning community is for students to feel that multiple perspectives and cultures are represented in the biology they are studying. Although it is not possible to represent aspects of all students' lives or the cultural background of each student in your course, careful attention to integrating culturally diverse and personally relevant connections to biology can demonstrate for students that diverse perspectives are valued in your biology classroom (Ladson-Billings, 1995 ▸). Most topics in biology can be connected in some way to the lived experiences of students, such as connecting what can be an abstract process of how genes produce traits to the very real and immediate example of cancer. Similarly, including examples that connect biology concepts that students are learning to different cultural communities—including both well-known stories like that of Henrietta Lacks and her connection to cell biology and smaller stories like that of Cynthia Lucero and her connection to osmosis—demonstrate to students that you as an instructor want to help them see themselves within the discipline of biology (Chamany, 2006 ▸; Chamany *et al.*, 2008 ▸). Finally, stories from both the history of science and present-day discoveries, when judiciously chosen, can convey that diverse populations of people can make key contributions in science (e.g., Brady, 2007 ▸). Value for the inclusion of diverse perspectives can also manifest in simply being explicit that much of the history of biology has not included diverse voices and that you as the instructor expect this generation of students to literally change the face of the biological sciences.

13. Work in Stations or Small Groups

To promote an inclusive community within the classroom, instructors can integrate opportunities for students to work in small groups during time spent within the larger class. For some students, participation in a whole-group conversation may be a persistently daunting experience. However, instructors can structure opportunities for such students to practice thinking and talking about biology by regularly engaging students in tasks that require students to work together in small groups. Care must be taken to be explicit with students about the goal of the group work and, whenever possible, to assign roles so that no student in a small group is left out (Johnson *et al.*, 1991 ▸, 1993 ▸, 1998 ▸; Tanner *et al.*, 2003 ▸). It can be challenging to design group work that is sufficiently complex so as to require the participation of all group members. Keeping group sizes as small as possible, no more than three or four students, can mitigate potential for unfairness caused by the act of putting students into groups. As one example, groups of students can be charged to bring expertise on a particular topic to class, check that expertise with others studying the same topic in a small group, and then be "jigsawed" into a new small group in which expertise from different topics can be shared (Clarke, 1994 ▸). Additionally, explicit statements from the instructor about expectations that group members will include and support one another in their work can be especially helpful. Finally, in smaller class sizes, an instructor can thoughtfully construct student groups so as to minimize isolating students of particular backgrounds (e.g., attempt to have more than one female or more than one student of color in a group) or interaction styles (e.g., attempt to place quieter students together so that they are likely to have more opportunity to talk). How instructors structure small-group interactions has the potential to provide a feeling of inclusion, community, and collaboration for students who may otherwise feel isolated in a biology classroom.

14. Use Varied Active-Learning Strategies

To engage the broadest population of students, instructors may be best served by using a variety of active-learning strategies from class session to class session. For each strategy, some students will be out of their comfort zones, and other students will be in their comfort zones. Students who may be more reflective in their learning may be most comfortable during reflective writing or thinking about a clicker question. Other students may prefer learning by talking with peers after a clicker question or in a whole class conversation. Still others may prefer the opportunity to evaluate animations and videos or represent their understanding of biology in more visual ways through drawing, concept mapping, or diagramming. One might ask which of these different strategies is the most effective way to teach a given topic, yet this question belies the likely importance of variations in the efficacy of different strategies with different students. There may not ever be a "best" way to teach a particular concept, given the diversity of students in any given classroom. The "best" way to teach equitably—providing access to biology for the largest number of students—may be to consistently provide multiple entry points into the conceptual material for students. The role of an instructor in creating an equitable learning environment that is accessible to all students is to make sure that no single population of students is always outside their comfort zone. If an instructor chooses a singular teaching approach—always lecturing or always concept mapping, regardless of the nature of the approach—it seems likely that the lack of variation could result in the alienation and exclusion from learning of a subpopulation of students. Additionally, using varied active-learning strategies may be key for individual learners to see a concept from multiple perspectives, make multiple associations between the concept and other ideas, and practice a variety of approaches to exploring that concept. By using varied active-learning strategies for each biological topic explored, instructors can work toward building an inclusive and equitable learning environment for a wide range of students with different approaches to learning.

15. Be Explicit about Promoting Access and Equity for *All* Students

Perhaps the most powerful teaching strategy in building an inclusive and equitable learning environment is for instructors to be explicit that the triad of access, fairness, and classroom equity is one of their key goals. There need not be substantial time spent on conveying this stance, but explicit statements by the instructor about the importance of diverse perspectives in science can make issues of fairness and equity explicit rather than an implicit. Instructors can share with students why they use the teaching strategies they do, for example, sharing the reasoning behind having students write to allow thinking and processing time for everyone. When an instructor publicly asserts that he or she wants and expects everyone in the classroom to be successful in learning biology, students can leave behind the commonly assumed idea that instructors are attempting to weed out students. Being explicit about one's goal of cultivating an inclusive, equitable, and fair classroom learning environment reiterates that students and instructors are on the same side, not on somehow opposing sides, of the teaching and learning process.

MONITORING (YOUR OWN AND STUDENTS') BEHAVIOR TO CULTIVATE DIVERGENT BIOLOGICAL THINKING

Science is fundamentally about negotiating models and ideas about how the natural world functions. As such, one might expect that undergraduate biology classrooms would mirror this negotiation and consideration of a variety of ideas about how the biological world might function. However, undergraduate biology classrooms have the reputation, likely deservedly, of being forums in which "right" answers—those already accepted as scientifically accurate—are the currency of conversation and the substrate for instructor–student dialogue. Yet research on learning suggests that inaccurate ideas, confusions, and alternative ideas about how the world works may, in fact, be one of our most powerful tools in the teaching and learning process (there are many publications on this subject, among them Posner *et al.*, 1982; National Research Council, 1999; Taber, 2001; Chi and Roscoe, 2002; DiSessa, 2002; Coley and Tanner, 2012). As such, it is important for instructors to cultivate discussion of divergent ideas in classroom conversations about biology—some of which may not be supported by current scientific evidence—as part of the process of moving students toward thinking in more scientifically accurate ways. Given the reputation of science courses as environments in which only those with correct answers are rewarded, biology instructors face the extra and very real challenge of gaining the trust of students to share divergent perspectives. Instructors can begin to establish a classroom community that values divergent ideas and promotes participation by students who may not already have scientifically accurate understanding by using the following four teaching strategies.

16. Ask Open-Ended Questions

One critical tool for instructors aspiring to cultivate divergent biological thinking in their classrooms is the use of open-ended questions, which are those questions that cannot be answered with a simple "yes" or "no" or even easily answered with a single word or phrase. Open-ended questions are by definition those which have multiple possible responses, such that inviting answers from a large group can yield more than an expected set of responses (Bloom *et al.*, 1956; Allen and Tanner, 2002; Crowe *et al.*, 2008). Open-ended questions can be posed orally to frame a class discussion and followed by a quick write or pair discussion to give students time to consider their responses. Alternatively, instructors can plan these questions in advance, so they can be given as brief homework assignments, allowing students time to consider the questions before coming to class. In general, open-ended questions require some design time and may not be easily improvised by most biology instructors. As research scientists, many of us have been trained to ask closed-ended questions, namely questions that drive an experimental design to either confirm or refute a stated hypothesis. In some ways, training in asking closed-ended, experimental questions may be at odds with developing skills in open-ended questioning. Prior to asking open-ended questions, instructors can attempt to anticipate the likely responses they may get from students. This serves the dual purpose of checking that the question is really all that open-ended, as well as preparing for how one will handle students sharing a wide variety of ideas, which may or may not be scientifically accurate.

17. Do Not Judge Responses

Undergraduate science classrooms in general have the reputation of being places in which only right answers are valued, and participation in class discussions has a competitive tone (Seymour and Hewitt, 2010). However, as instructors, we have the power to encourage all students—not just those who have already constructed biologically accurate ideas—to exercise their voices in our undergraduate biology courses and to make their thinking about biology visible. To create a safe environment that encourages students to share all of their ideas, instructors may be best served in acknowledging student responses as neutrally as possible. This does not require inadvertently supporting a scientifically inaccurate idea. Clearly stating "I'd like to hear from a number of us about our thinking on this, and then we can sort out what we are sure of and what we are confused about," sets the stage that all the responses may not be correct. Even the most simple "Thanks for sharing your ideas" after each student responds, without any immediate judgment on the correctness of the comments, can set a culture of sharing that has the potential to significantly expand the number of students willing to verbally participate. Any incorrect statements that are shared can be returned to at a later point in the same class or the next class and considered generally, so the individual student who happened to share the idea is not penalized for sharing. If one student shares an inaccurate idea, no doubt many more hold similar ideas. Some instructors may worry that allowing a scientifically inaccurate statement of misconception to be said aloud in a classroom will mislead other students, but there is ample evidence that just because statements are made in a classroom, even by instructors, these are not necessarily heard or learned (Hake, 1998 ▸).

18. Use Praise with Caution

For instructors new to actively engaging students during class time, or even for seasoned instructors in the first few weeks of a term, it can be challenging to cultivate student participation in whole-group discussions. In response to those students who do share, instructors can unwittingly work against themselves by heaping praise on participating students. "Fabulous answer!" "Exactly!" "That's perfect!" With very few syllables spent, instructors may inadvertently convey to the rest of the students who are not participating that the response given was so wonderful that it is impossible to build on or exceed. Additionally, in a short period of time, the few students who are willing to participate early in a discussion or the course will become high status in the classroom, those who have reaped the instructors' praise. Research from sociologist Elizabeth Cohen and her colleagues, described as "complex instruction," has explored the power instructors have of effectively assigning academic status to students simply by the nature and enthusiasm of their remarks about those students' responses (Cohen, 1994 ▸). So, does this mean instructors should never praise student responses? No. However, it suggests using praise with caution is essential, so other students feel that they still have something to add and can be successful in sharing.

19. Establish Classroom Community Norms

As instructors strive to cultivate a classroom in which divergent and not always scientifically accurate ideas are shared, it is critical that the instructor also establish a set of classroom community norms. In this case, "norms" refers to a set of accepted usual, typical, standard acceptable behaviors in the classroom. Common group norms established by experienced instructors include the following: "Everyone here has something to learn." "Everyone here is expected to support their colleagues in identifying and clarifying their confusions about biology." "All ideas shared during class will be treated respectfully." For many instructors, these classroom norms are simply verbally asserted from the first few days of a class and then regularly reiterated as the term progresses. Importantly, students will observe directly whether the instructor enforces the stated group norms and will behave accordingly. As such, it is important to decide what norms you are comfortable enforcing as the instructor in charge of your classroom. It only takes one student experiencing ridicule from a fellow student based on what they shared (someone shouts out, "That is totally not how it works!") to immediately bring to a halt other students sharing their ideas in class. When such incidents occur, and they will, a simple reminder of the group norms and public reassurance and support for the student made to feel uncomfortable can go a long way. Simply using language like, "Could you please keep sharing your ideas? I have no doubt that if you are thinking along these lines, lots of smart people would think that way, too." Establishing early and regularly enforcing a supportive classroom culture—just as you would in an effective and productive research lab meeting, study section, or any other gathering of scientists—is essential to maintaining an equitable, inclusive, and welcome classroom community.

TEACHING *ALL* THE STUDENTS IN YOUR CLASSROOM

As asserted above, perhaps the most underappreciated variables in teaching and learning are the students themselves and all their individual variations. Although it may be tempting to generalize what students will be like from semester to semester, from course to course, and from institution to institution, there is little evidence to support these generalizations. To promote student engagement and strive for classroom equity, it is essential to constantly and iteratively attend to who exactly is in your classroom trying to learn biology. Below are two specific strategies to help keep the focus of your teaching on the actual students who are currently enrolled in the course you are teaching.

20. Teach Them from the Moment They Arrive

As biology instructors, we assume that the only thing being learned in our classrooms is biology. However, student learning does not begin and end with the biology being explored and discussed. Increasingly, research from a host of fields—educational psychology, sociology, and science education—suggests that learning is not discrete and delimited by concepts under study, but rather continuous and pervasive. Learning is happening about everything going on in the classroom. As such, instructors are best served by considering what students are learning, not just about the subject matter, but also about culture of the classroom from the moment they enter the room. Consider students' opportunities to learn about classroom culture in just two of many ways: students' impression on the first day of class and students' impressions as they enter the classroom for each class session. What an instructor chooses to do on the first day of a course likely sends a strong message to students about the goals of the course, the role of the instructor, and the role of the students. If one wants to convey to students that the course is about learning biology, then reading the syllabus and spending the first class session discussing how grades are assigned is incongruous. Without intent, this instructor is implicitly teaching students that the course is primarily about assigning grades. If the course is about learning biology, then instructors can implicitly and explicitly teach this by engaging students in exciting, intellectually challenging, and rewarding experiences about biology on the first day of a course. Similarly, if an instructor has as a goal that verbal participation by students is key to success in the course, then *all* students should be engaged in and experience talking about biology from the very first day of class. More subtly, students will also likely learn about their role in the course and their relationship with the instructor based on seemingly inconsequential day-to-day interactions. If an instructor stands at the front of the room or works on his or her computer while waiting for class to start, students may inadvertently "learn" that the instructor is not interested in students or is inaccessible or too busy to be approached, even though this may not be the conscious intention of the instructor. Similarly, students will likely notice whether the instructor regularly speaks to the same subset of students prior to class each day. In all these cases, instructors can make conscious efforts to convey their interest in and commitment to the learning of all students in the course all the time—before class, during class, after class, via email. If we want to teach them about biology, we likely need to be teaching them about the culture of our classrooms and their role in it at the same time.

21. Collect Assessment Evidence from Every Student, Every Class

To accomplish the goal of teaching those actual students who are sitting in front of you, it is essential to maximize the flow of information from individual students to the instructor. Frequent collection of assessment evidence—about students' biological ideas, about their reflections on their learning, about their struggles in the course—is essential for instructors to know the learners they are trying to teach. Beginning immediately, instructors can start with an online "More about You" survey as homework on the first day of a course and can continue to collect information about students throughout the semester (Tanner, 2011 ▸). For many instructors, this is most easily accomplished through student online submission of writing assignments. Other options include the use of daily minute papers or index cards, clickers, and a variety of other assessment tools (Angelo and Cross, 1993 ▸; Huba and Freed, 2000 ▸). While the nature of the assessment evidence may vary from class session to class session, the evidence collected from each and every student in a course can aid instructors in continuously re-evaluating student ideas and iteratively changing the arc of the course to best support the learning of that course's student population. The goal is to assure a constant stream of information from student to instructor, and for each and every student, not just those confident enough to speak up publicly during class.

Regular consideration of classroom evidence is foundational for bringing our scientific skills to bear on our teaching.

CONCLUSION

As instructors, we have the power in our classrooms to choose to attend explicitly to issues of access, inclusiveness, fairness, and equity. The strategies presented above are merely starting points from which instructors can step up their attempts to cultivate equitable classroom environments that promote student engagement and participation in learning biology. No doubt this list of equitable teaching strategies could be much longer, and readers are encouraged to record additions that they discover or invent themselves that address the goal of promoting equity and access for *all* the students in our biology classrooms.

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