

Feature

Approaches to Biology Teaching and Learning

Order Matters: Using the 5E Model to Align Teaching with How People Learn

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INTRODUCTION

“I have to teach someone to make a peanut butter and jelly sandwich. How am I supposed to do that? What should I start with? How can this be so hard?”

I have found that teaching anything to another person is rife with far more decisions and dilemmas than I could have ever imagined at first. Years ago, I had a college roommate who wanted to participate in a summer teaching program. For her interview, she had to develop a lesson plan to teach someone else how to make a peanut butter and jelly sandwich. Have you ever thought about teaching someone else how to make a peanut butter and jelly sandwich? She had asked for my input, and once we started to really consider the possibilities, our minds reeled. How would you start? What would you do first? Next? After that? Who was the learner anyway? And had they made a sandwich before? Were they allergic to peanuts? How old were they? Should we let them have a knife? Should we show them how first? Talk them through it? Let them have a go at it on their own? Should we first teach them the names of all the tools and things we were going to use? Should we ask them why they needed to learn how to make a peanut butter and jelly sandwich in the first place? What were the critical issues in teaching someone how to make a peanut butter and jelly sandwich?

Much like in the “PBJ Dilemma” as we came to call it, there are many decisions to be made in designing effective learning experiences in undergraduate biology classes—and instructors are making these decisions constantly. It can seem overwhelming, yet the research literatures from cognitive science, psychology, and science education about how people learn suggest guidelines about constructing effective learning experiences (National Research Council [NRC],

1999). Much like the PBJ Dilemma, the *order* in which we decide to do things with students when we teach is critical, yet the *order* of things happening in a class session often goes undiscussed and unexamined. At first glance, the most pressing teaching dilemmas in our biology classrooms—student motivation, student retention of information, student understanding of difficult concepts—may seem unrelated to the *order* in which things are happening; however, what we do first, second, third, and so on can have many ramifications. For many instructors who have primarily learned from and used a lecture-based teaching approach, considerations of order have been primarily about the order of ideas. With the increasing use of active-learning strategies, class sessions are moving from having a single component—a lecture—to having many components over the course of even 50 minutes (e.g., a video clip, a pair discussion on a biology-based problem, a clicker question, a mini-lecture, and a final index card reflection). So, what is the optimal order for sequencing these elements to maximize student learning of biology?

CONSIDERING THE COMPONENTS OF A CLASS SESSION AND THEIR ORDER

Consider the last class session you taught, whether it was a lecture class, a seminar, or a laboratory session. What were all the components of that class session? Did you lecture? Did the students engage in a small group discussion? Did you introduce new terms or ideas? Did students take a quiz or exam? Did they conduct an experiment? Did they answer one or more questions in writing? How many different components were there in that class session? Now, think about the order in which these things happened. Did you specifically choose to have things happen in this particular order? If so, how did you decide what came first, last, and in between?

One tool available to instructors is the 5E model, a planning tool for instructors proposed by science educator Roger Bybee and colleagues at BSCS (formerly known as the Biological Sciences Curriculum Study). It has been used to develop many BSCS curricular materials and textbooks for

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biology teaching and learning, as well as to educate current and aspiring K–12 teachers about lesson planning. The 5E model is an attempt to translate what is known from research in a variety of disciplines about how humans learn—from cognitive science, psychology, and science education—into a tool that can guide instructors in planning effective learning experiences for students.

A BRIEF INTRODUCTION TO HOW PEOPLE LEARN, LEARNING CYCLES, AND THE 5E MODEL

The NRC's *How People Learn* has synthesized decades of research across many different disciplines about how people learn (NRC, 1999). Key findings from that synthesis include the following. First, students (people) must be interested and engaged in what they are learning and find it useful and meaningful. Second, students (people) must be actively involved in the process of teaching and learning, comparing new information to previous ideas, constructing new understandings, and quite simply changing their own minds about how the world works. And third, students (people) need opportunities to apply what they have learned to new situations, to check the completeness of their understanding, and to evaluate their own learning for themselves. Specifically, the NRC offers the following:

An alternative to simply progressing through a series of exercises that derive from a scope and sequence chart [a textbook or curriculum] is to expose students to the major patterns of a subject domain as they arise naturally in problem situations. Activities can be structured so that students are able to explore, explain, extend, and evaluate their progress. Ideas are best introduced when students see a need or a reason for their use—this helps them see relevant uses of the knowledge to make sense of what they are learning. (NRC, 1999, p. 127).

The idea that there is an order of events—termed a learning cycle—that should optimally occur in the process of human learning is not new (Dewey, 1971). In 1962, science educators J. Myron (Mike) Atkin and Robert Karplus argued influentially that effective learning cycles involved three key components: exploration, term introduction, and concept application (Atkin and Karplus, 1962). In their scheme, exploration allowed the learners to become interested in the subject at hand, raise questions, and identify points of dissatisfaction with their current understanding. Introduction of new ideas and terms, primarily by the instructor, but negotiated by both instructor and students, followed. Finally, concept application provided learners with opportunities within the classroom to apply their new ideas, try out their new understandings in novel contexts, and evaluate the completeness of their understanding.

Bybee and his BSCS colleagues described the 5E model as a “direct descendant of the Atkin and Karplus learning cycle” and suggested the following expanded sequence of key elements of an effective lesson:

1. Engagement
2. Exploration

3. Explanation
4. Elaboration
5. Evaluation

What is unique about the 5E model is that Bybee and colleagues translated decades of research into a brief and memorable set of five words that instructors could actually remember and use (Trowbridge and Bybee, 1996; Bybee *et al.*, 2006). The 5E model team reasoned that to have significant impact on classroom instruction, a model would need to have a more tool-like quality than most scholarly models did at the time (Bybee *et al.*, 2006). The 5E model is based on both a conceptual change model of learning and a constructivist view of learning. The former asserts that for conceptual learning and enduring understanding to occur, the learner must become aware of and dissatisfied with their prior ideas about a topic, become receptive to new ideas, and then integrate new information encountered in a classroom into their existing conceptual framework (Posner *et al.*, 1982). The latter posits that the student, not the instructor, has to do the work of identifying and changing their conceptions (Piaget, 1950, Vygotsky, 1978, Bruner, 1961). Finally, because the 5E model suggests that any instruction should have multiple components, it also leads the instructor to design learning environments that are accessible to students with a variety of different learning styles and preferences (see Tanner and Allen, 2004 for review).

Below, I briefly introduce each of the five components of the 5E model, including the original description of what teachers and students are doing during each phase and information that may aid instructors in seeing how this might apply to their own undergraduate biology classroom.

ENGAGEMENT (ENGAGE)

The teacher or a curriculum task accesses the learners' prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students' thinking toward the learning outcomes of current activities. (Bybee *et al.*, 2006).

While there is ample evidence that learning has affective components and is more likely to occur when students are engaged in the material, instructors often skip this first phase of the 5E model. The goals of the Engagement phase are to invite the learner's consideration, encourage their interest, spur them to unearth their prior experiences with the concepts about to be studied, and pique their interest to know more. Some educators rely on “discrepant events” to accomplish these goals, using surprising or unusual examples related to the upcoming concepts to spark learners' interest. Other instructors explicitly use preassessment questions during the Engagement phase, not only to elicit student thinking about their prior knowledge of the subject but also to systematically collect information on all students' ideas to guide instruction.

The Engagement phase most often happens at the beginning of a class session, but this need not be the case. For example, Engagement can be structured through a home-

work assignment due just before a new conceptual unit is to begin. This assignment can be a reading from the popular press, a website to explore, or a video to watch. It can be an assignment to find a recent news article relevant to an upcoming unit on evolution, a personal reflection on how cancer has influenced their lives, or a question that requires students to examine their prior knowledge and assumptions about the upcoming topic. With the advent of online learning systems, assigned Engagement activities due before the class session can be read in advance by the instructor and used as the basis of activities in class.

EXPLORATION (EXPLORE)

Exploration experiences provide students with a common base of activities within which current concepts (particularly misconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation. (Bybee *et al.*, 2006).

Here instructors construct situations in which students grapple with a problem and attempt to understand the material at hand on their own or in groups. Students often encounter confusion, conflicting ideas, or unanswered questions during this phase. Exploration is an opportunity for student meta-cognition, namely a chance for students to think about what they do and do not understand conceptually about the topic and identify gaps in their understanding. It provides an opportunity to increase student interest, elevate their need to know, and articulate their questions. Exploration should occur before any Explanation or introduction of new terms or information, so that students are primed and ready to entertain new information, explanations, and ideas (Posner *et al.*, 1982). In a lecture setting, this Exploration phase may be the opportunity to generate questions or struggle with a biological problem. In a laboratory, this Exploration phase may be the beginning portion of a laboratory investigation.

EXPLANATION (EXPLAIN)

The explanation phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase. (Bybee *et al.*, 2006).

All aspects of the 5E model assume active participation by students, and the Explain phase is no different. Optimally, the Explanation phase involves active participation by both instructor and students. In college and university science classrooms, the Explanation phase is likely most often an instructor-led lecture. It is a time for introduction of common terms that provide students entry into the language of

science. In addition, it is the time that students are inculcated into how scientists in the past have categorized, labeled, and considered the biological entities being discussed. In addition, it is a time that the instructor (with students) can address questions and confusions and ideas that have arisen in the process of Exploration. Research on learning would suggest that after priming their minds in the Exploration phase, students are more likely to have questions and confusions that can make lectures more meaningful, interactive, and participatory. The Explanation phase may also include a variety of peer teaching and learning activities (e.g., jigsaw discussions [Clarke, 1994]).

ELABORATION (ELABORATE)

Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities. (Bybee *et al.*, 2006).

A major goal in science education is for students not only to master the biological concepts being presented, but also be able to apply those ideas appropriately to novel contexts and situations. During the Elaboration phase, instructors explicitly guide students in how to do this and give them opportunities to practice the application of their new understandings. Placed after the Explanation phase—which should have addressed students' confusions, introduced new terms and ideas, and led to some conceptual resolution—the Elaboration phase lets students try out their new knowledge. Elaboration can include the assignment of new biology problems in new contexts, design of the next step of an investigation, or any of a number of other assignments and projects that follow the Explanation phase but precede formal Evaluation of student learning.

EVALUATION (EVALUATE)

The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives. (Bybee *et al.*, 2006).

The Evaluation phase is perhaps the most familiar to college science faculty and easily recognizable in current teaching practices. During Evaluation instructors provide opportunities for students to reflect on and demonstrate their understanding or mastery of the concepts and skills that have been explored. While Evaluation can be an in-class quiz or exam, it need not be limited to these modalities. Evaluation can be the development and/or presentation of a product such as a poster reporting on a lab investigation, a pamphlet to educate others about the biological basis of a disease, or a final paper with a critical analysis of a research journal article.

Research on the impact of using learning cycle models—such as the 5E model and its predecessors—has been conducted in a variety of disciplines and teaching contexts from elementary school through college (e.g., Linn and Their,

1975; Renner and Paske, 1977; Lowery *et al.*, 1980). Lawson examined and synthesized the results of more than 50 such research studies and found that many documented improvement in students' conceptual understanding and scientific reasoning, as well as more positive attitudes toward science among students (Lawson, 1995; Lawson, 2001).

REVISITING THE ORDER OF YOUR LAST CLASS SESSION

So, let's return to the last class session that you taught (see above). What were all the components of that class session (e.g., lecture, small group discussion, clicker question, quiz, investigation)? In considering what you've just read about the 5E model, which of these components would you classify as including Engage activities? Explore activities? Explain activities? Elaborate activities? Evaluation activities? In what order did they occur? How well does that order reflect the 5E model? You may already be using these elements, without being aware of the formal construct. In what ways might you adjust your usual classroom plan to bring the order of things more into alignment with the arc of how most people learn?

STRATEGIES FOR USING THE 5E MODEL TO ALIGN TEACHING WITH LEARNING

Making every classroom session that we teach conform to a 5E approach is not the goal; rather we wish to use the 5E model to look at the extent to which the order of the learning experiences we are using aligns with what is known about maximizing student learning. A variety of instructor challenges may be addressed in this way, as illustrated below.

Instructor Dilemmas

"I've heard about all these innovative teaching strategies being used in biology, but I just don't know where to start to change from only lecturing."

"I feel like I have all sorts of teaching tools that I've learned about, but I can't figure out when to use which ones."

Potential 5E Strategy: Design class sessions to have at least two components of the 5E model, even if you can't hit all five in a given class meeting

Start small, for example by adding an Engage activity where students write and think about what they already know before the lecture. It can take as little as 2–3 minutes. If you'd like to give them a chance to Explore these ideas with their colleagues, try using a think-pair-share (Smith *et al.*, 2009; Tanner, 2009) for 3–5 minutes. Alternatively, ask students to write down the "muddiest point" or "most confusing point" during your lecture and have students hand that in as an Evaluation exit ticket at the end of class. In large classes that number in the hundreds, reading even 10% of these "muddiest point" Evaluations can give you insights into where and how to start the next class most usefully. For many instructors, the first step in applying the 5E model is to add any one other component to their classroom plan in addition to using the lecture to Explain.

Instructor Dilemmas

"I don't have time to connect the biology I teach to real life. I have too much to cover to do that. And it's not needed—majors are already inherently interested in the biology I'm teaching."

"What I'm about to tell students is not something they're going to have any prior experience with, so it doesn't make sense to ask students to think about what they know before I start lecturing."

Potential 5E Strategy: Start your class session with something that Engages students and/or elicits their prior knowledge

Based on what is known about learning, engaging students is essential for good results and it can take as little as 5 minutes. While majors and nonmajors may have different career goals in relationship to biology, they are all still humans who need to see the rationale for and relevance of the material at hand, as captured in the ever-present refrain of "Why do I need to know this!?" Engaging students can be as simple as asking them what they already know about the day's topic before you start; this strategy has the bonus of revealing what students already know (Allen and Tanner, 2002). Asking students to evaluate a challenge statement—a statement based on a common misconception—can be useful for getting students to realize that they still have things to learn. Additionally, Engage activities can include brief demonstrations, personal stories, a current events story, and/or a video clip or television advertisement pertinent to the biological topic at hand, as well as a problem scenario or assessment question. Finally, the Engage activity for a new unit or topic can come at the end of the previous class session, especially if you are trying to find out what students already know, or in the form of a homework assignment that challenges them to find a news report relevant to the next class topic.

Instructor Dilemmas

"I usually start my lab section with an introductory lecture that lasts 30–45 minutes, but students rarely ask any questions until we're halfway through the lab."

"I've tried to get students talking at the end of class after I lecture. I give them all the information they would need before I ask them to talk, but then they don't seem to have anything to say."

Potential 5E Strategy: Allow for at least some Exploration before you begin an Explanation

It is often a challenge for students to appreciate the gems of wisdom that instructors tell them because they don't see the usefulness of the information. Allowing students at least a short amount of Exploration time to attempt to solve a problem, make a prediction about an experiment, or answer a complex question before any instructor-led Explanation can prime students to be ready to receive new information. In the case of the laboratory class, this may mean that only brief instruction or a demonstration is used at the beginning of a lab; the instructor then waits and watches for most students to recognize the challenges and only then delivers

a mini-lecture just when students are most in need of new information. Similarly, interleaving student discussion with lecture can provide short thought-Explorations in which students can identify their questions and confusions and then be ready and looking for the answers to those questions during the lecture. So, consider placing mini-lectures in the middle or at the end of class sessions, as opposed to at the beginning. Allow for Exploration time before you begin new Explanation.

Instructor Dilemmas

“Students in office hours tell me that they understand what I’m saying during lecture, but as soon as they go home they’re confused again.”

“I construct test questions so that my students will have to apply the concepts they’ve learned to do well on the exam, and I don’t understand why they always seem to do so poorly on these questions.”

Potential 5E Strategy: Build in exercises that require students to practice Elaboration and apply concepts to new situations before they encounter that challenge on exams

We have all likely had the experience of understanding something so clearly upon listening to an expert explain it and then, in the quiet of our own minds, being unable to reconstruct the ideas and why they were so insightful at a later point. Such is the experience of novices in biology classes on a regular basis. As instructors, we recognize that providing students with structured opportunities to Elaborate on what they have learned and apply it in new contexts is a critical part of teaching. Yet, so often, the Elaboration phase of learning is left to students to figure out outside of class. Elaboration activities can be as simple as giving students another chance to grapple with a problem or challenge that was used as an initial Engage or Explore activity. It can happen inside the classroom or can be a homework assignment, in particular by giving students the challenging, higher-order questions that you want them to be able to answer on the exams. Some instructors give students all the questions that will be on the exams at the beginning of the semester, telling students that these are the types of situations they need to be able to think through. Good questions not only give students Elaboration activities in advance, they also help students to recognize the kinds of information they should be looking for in lectures and class activities to help them grapple with the complex, applied questions that arise on exams and in life.

Instructor Dilemmas

“By the time I figure out what my students don’t understand while grading the exams, it’s too late to go back and change anything.”

“I often leave my lectures not really sure what the students got and didn’t get.”

Potential 5E Strategy: Collect some form of Evaluation evidence every class session

Evaluation of student thinking and learning does not always require a formal exam, graded in detail! Something as simple as a minute paper on an index card, a drawing activity, a low-stakes, ungraded clicker question, or a weekly reflective journal entry through an online system are all simple ways to regularly include Evaluation of student thinking into classroom teaching. However, this regularity also demands a different instructor stance with respect to grading. Not all of the Evaluation evidence (assessments) collected from students needs to be graded. Points can be given for effort and completion of assignments, regardless of the correctness of the results. In fact, grading all student evidence collected discourages students from revealing confusions and questions, which is essential for their learning. Regular integration of Evaluation components into classes will not only provide opportunities for students to self-evaluate their understanding but also give the instructor insights that can direct the focus and flow of upcoming class sessions.

Given the ideas described above, how might the 5E approach guide small changes in how you structure a series of learning experiences in one of your classes? How could you add a brief component to your existing class session plan that would Engage students by revealing the relevance of the material to their own lives? What might it look like to give students time to Explore the concept at hand and identify their confusions before beginning a lecture Explanation about that material? And when, before the day of the exam, could students be challenged to Elaborate on their new knowledge, revise old ideas, and apply their new understandings in new contexts? Note that the order of teaching and learning suggested by the 5E model is often different from what students are used to experiencing. As such, it is often helpful to be explicit with students about what you are doing, in what order, and why, and to let them know that the approach is based on research about how students like themselves can best learn biology.

IN CONCLUSION

Though the 5E model was developed primarily to aid K–12 science teachers in achieving more effective lesson planning and teaching, its grounding in what is known about how humans learn makes it widely applicable to instruction of students at all cognitive levels. In addition, the 5E approach can be used in developing a research seminar, a lab meeting structure, a conference sharing session, a faculty meeting, a negotiation session with an administrator, or any other venue where you want one or more humans to leave with different ideas than they began with. Higher education researcher James Fairweather has argued that the changes in college and university biology teaching need not be big changes to have a profound impact (Fairweather, 2008). Consideration of the order of events happening in classrooms using the 5E model can point us in the direction of just these kinds of small changes.

POSTSCRIPT

This Approaches to Biology Teaching and Learning feature was constructed with the 5E model in mind. The opening quotation and PBJ Dilemma are meant to Engage the reader, indicating what types of teaching frustrations the article will address. The charge to the reader in the second section to consider the structure and order of their last teaching session prompts a thought-based Exploration about the concepts at hand in the reader's own context. The introduction of the brief history of learning cycles, how people learn, and the components of the 5E model introduces the reader to new terms and ideas and is a one-sided Explanation phase. The second charge to the reader to revisit their last class session and its order, along with the articulation of several starting strategies for using the 5E model in college science teaching, serves as a prompt for an Elaboration exercise by the reader. And finally, the conclusion section offers questions for the reader as more of a self-evaluation than an Evaluation of the effectiveness of this article per se. I would appreciate you sharing your own Evaluation of this article with me, either the next time our paths cross in person or through email (kdtanner@sfsu.edu)!

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