Active Learning of Biochemistry Made Easy (for the Teacher)

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So Much Information, So Little Time

The number of biochemistry facts keeps increasing at a substantial rate. How can a biochemistry teacher best present the most important and useful information about where biochemistry has been, is now, and where it is going? And how can that best be done in 35–40 (or 70–80 in this case) lecture hours? This paper addresses the problem. Let us divide it into two parts, content and form, and consider each separately.

Biochemistry Content Constraints

There are far too many biochemical facts for anyone (let alone any student) to learn them all *(1),* so choices must be made. Most teachers choose their facts by selecting a textbook and/or producing their own fact-filled lecture notes. However, educators generally agree that studying concepts and principles (rather than facts) produces superior learning *(2).* This is particularly important for the molecular life sciences where the fundamentals are largely understood, but the facts can be overwhelming. Therefore, material to be learned should focus on biochemical principles and concepts, rather than rote memorization of lecture material *(3, 4),* with illustrative facts brought in to make the concepts real. That, of course, sounds easier than it actually is, in part because most teachers lecture, and lecturing does not promote such higher order learning *(5).*

Biochemistry Pedagogy Constraints

The second part of the problem, form, has an apparently direct solution: active learning methods *(6–13).* As King *(14)* put it succinctly, the "guide on the side" is an improvement over the "sage on the stage". Silva and Batista *(15)* have pointed out the desirability of promoting active learning methodologies for biochemistry teaching.

Developing an Effective Solution

We tend to teach the way we were taught, so lecturing prevails. What plan might be created to produce widespread change?

In designing a plan, I tried to adhere to two precepts:

1. Implementation by teachers would have to involve the absolutely lowest possible activation energy. No "teacher transformation" *(11, 16)* should be required. Ideally, the method would be easier for instructors than lecturing. The aim here was to elicit wide interest and to achieve broad acceptance because all of the good ideas in the world will not produce change if the change is too much trouble to implement.
2. Students should learn better, if not more. Most biochemistry courses appear to overload students with information *(1, 17).* But each student has an individual limit for weekly information assimilation above which repulsion becomes overwhelming. Thus, if there is no way to have the students learn more facts, perhaps we should try to help them learn more important things.

To achieve those precepts, the following method was developed and implemented at Texas Christian University (TCU). One chair at one side of the classroom was rotated 90° so that its back is to the wall. This is the only "technology" necessary to initiate the process: one chair in the classroom that is not fixed to the floor. This is where the Instructor sits, literally becoming "the guide on the side". This permits the responsibilities of the participants to be redefined as described below. This active learning dynamic is used for every class except examinations.

Responsibilities of the Discussion Leader

Students take turns being the Discussion Leader (DL). The DL sits at the head of the class, occupying the traditional position of the Instructor. Each DL, like everyone else in the room, knows in advance what material she or he is responsible for because the Instructor has distributed a syllabus *(18)* and assigned topics to individual students at the start of each semester. The job of the DL is to prepare one or two "generic questions" in King's terminology *(14)* per classmate (or, in large classes, enough questions to cover the material well in 50 minutes), which aim to elicit answers covering concepts, principles, and other important points in the material. DLs are evaluated by the Instructor on the basis of the number and quality of the questions produced and how well they lead the class; for example, if a DL omits questions about important concepts, then he or she would lose points. During a discussion on protein folding, two questions might be "What is the inverted bumpy free energy cone?" and "What is the connection between different sized proteins and different sized bumps?" This list of questions is passed out at the start of the class, and the students are not allowed to see them before the class starts. It is beneficial for the DL to show them to the Instructor in advance, however.

Responsibilities of the Other Students

Students who are not the DL are responsible for checking the syllabus to find what material is to be covered in class and learning the material *in advance* well enough to prepare a one or two page summary of the most important points ("Good Things To Know"). Students bring these pages to class, use them (if necessary) to answer the DL's questions, annotate them in class to improve them as necessary, and turn them in to the Instructor for credit (3–4 points). In large classes or classes with few or low quality teaching assistants (TAs), it may be necessary for the students to instead turn in a distillation (the "Essence") of the Good Things To Know to ease grading work loads.

During classes, DLs ask questions from their lists to the whole class, and students answer them for credit (participation points, 1–2 points). Students also can earn participation credit for raising the level of the discussion in ways such as asking good questions of their own, providing new information or insights (admittedly, a rare yet welcome occurrence), and so forth. This enlivens the discussion and ensures that all students pay attention throughout the entire class. At the end of class, students

turn in their page(s) and receive a grade based on the quality of their answers to questions, and so forth (again, 1–2 points) plus the quality of their Good Things To Know pages (again, 3–4 points). In these small classes, decisions about what is important or not important are made entirely by the Instructor. Because students have had the opportunity to improve their pages in class, they should receive full marks, though they sometimes leave out important points or do not correct misunderstandings and then suffer the consequences. DLs (like their classmates) receive up to 5 points based upon the quality and quantity of their questions. Overall, 445 points total are available in each course: 5 points per class meeting, so that $5 \times 39 = 195$ total points for classroom activities; 50 points are available for each of the three course exams; and 100 points can be earned on the final examination.

Responsibilities of the Instructor

The Instructor awards and records credit for correct answers provided by the students to the DL's questions (again, 1–2 points), clarifies answers as necessary, sometimes by asking additional questions (e.g., "What do the bumps in the cone represent?"), emphasizes important points, mentions new and relevant research, steers the students back on track when they go astray, and generally shepherds each class period to maximize learning of the agreed-upon most important material. At the end of each class, it is essential that the Instructor summarizes the important points, principles, and concepts, fills in any gaps, and provides an introduction for the next topic. Such a review and summary greatly aids student learning.

Of course, Instructors will modify this method for their own convenience, and there will be ups and downs during implementation. But controlled comparison of this method with lecturing may show the former to improve higher-level learning and retention over time.

Advantages of This Active Learning Technique

Rearranging the class dynamics in this way produces several important results, both for instructors and students. These advantages are outlined below.

For Instructors

- It is a step toward active learning, and it is an easy step.
- Instructors are under less pressure to perform because they are not required to lecture.
- This active learning technique entails almost no changes concerning the physicality of the classroom.
- Everyone naturally becomes part of the learning team that creates the annotated summaries.
- Students learn important information better *(19)* than when they are lectured to or talked at and will usually take notes until they lose interest, which typically begins to occur after about 15 minutes *(20, 21)*.

For Students

- This rearrangement puts responsibility for learning squarely in the students' own hands. They must figure out what is important and why it is important, and they must convey this information in concise writing and well-stated oral answers during class.
- They distill the concepts, principles, and most important points and write them down in their own words.
- Summary preparation makes students actively process the assigned information before they come to class.
- The annotated summary and important points pages, which the students use to study for exams, contain the essential material. The Good Things to Know and Essence are pages that, by the nature of the process, are agreed upon by all to contain the most important materials to be learned. Students can always learn facts and extra details after they have learned the essential material on their synopsis pages, if they have time.
- At TCU, all students are required to take a certain number of courses that provide them with writing credit. Frequently, it is difficult for science majors to take all their required courses, obtain enough writing credits, and still graduate in four years. Because students do so much writing with this revised format, it was easy to obtain writing credit from the appropriate University committees for both semesters of this sequence.

Disadvantages of This Active Learning Technique

The principal disadvantage is that Instructors (or TAs) must look over the Good Things To Know or Essences, assign and record grades, and return them by the next class, so the students can use them to study for examinations. Obviously, the more students' writing that must be read, the longer it will take to read, grade, and return the synopses. In classes with small numbers of students (up to about 30), it should not be too onerous for the Instructor to read and grade a page or two per student per class period, so long as the size of the type and page margins are clearly specified in advance. For large classes, students can be required to first prepare their Good Things To Know pages to use in class and then condense them down further into the five or ten most important things they learned from the material (the Essence) to turn in for credit. In that way, the Instructors' burden of reading students' writing can be reduced without taking the focus away from the students concentrating on learning principles and concepts.

The other significant disadvantage that appears occasionally is that some students prefer to be lectured to because "We aren't paying all this money to teach ourselves". I suggest how to deal with that problem next.

Caveats

Some students expect to be told what to know. Perhaps they are tired of thinking. Point out that this paradigm (and variations) is widely used in their other (nonscience) classes, for which students pay willingly.

To be successful, three things must be made clear at the first class meeting:

1. This instructional method is a variant of what happens in many of students' nonscience classes, though students may not have experienced active learning techniques in other science classes.

2. The instructor will be scrupulously fair by giving all students equal opportunities to earn points in class. In large classes, this may necessitate using a seating chart so that the DL can begin asking questions where the previous DL left off.

3. Active learning gives students better, longer-lasting learning. Distribute references attesting to the benefits of active learning (e.g., *6–14, 22–27*). The students may or may not look at the references, but giving science students hard data *should* turn them into believers.

It is not desirable for the students to prepare two copies of their synopsis and turn one in because it may be difficult for the students to annotate two sets of notes in class. Carroll *(28)* has mentioned the importance of allowing enough time in class for taking good notes.

Syllabus topics naturally vary in the numbers of concepts each contain. Material introducing amino acids, saccharides, or lipids do not contain as many concepts as material covering signal transduction; this, too, needs to be explained in advance. Students cannot be expected to ask questions about principles and concepts that do not exist in the material. For such "vocabulary" classes, successful completion of tasks such as "draw the complete covalent structure of arginine" should merit participation credit.

This technique might work for other small, upper-division science courses where most or all of the principles and concepts have been elucidated, although it probably would be less successful in lower-division courses. However, the technique in this simple form has not been tested in any courses other than these two biochemistry courses, so this supposition is extrapolation on the part of the author.

Note well that biochemistry is complicated and the instructor should set aside time at the end of each class to help students generate a list of the most important principles and concepts that must be learned. Students need training to see the big picture.

Conclusions

This simple and straightforward alteration of class dynamics may be an easy way to improve a traditional lecture-based approach to instruction. Students reported *(29)* that it sufficiently prepared them to demonstrate knowledge in areas identified specifically in the course objectives. Therefore, this model is submitted for evaluation by the chemistry community so that needed controlled studies can be performed with larger student numbers to provide evidence concerning the value of the method and its transfer to other populations.

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