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Active Learning and Cooperative Learning in the Organic Chemistry Lecture Class

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Background

During the past decade there has been much discussion in the science education literature about the implementation in college science classes of teaching techniques that have been widely used in precollege education (*1*). These strategies include cooperative learning (*2*), classroom assessment (*3*), inquiry learning (*4*), and active learning (*5*). Despite this interest in new teaching methods, the majority of college science classes are still taught in a predominantly lecture format. There are many reasons for this and some of them have been discussed in the literature (*6*). The reasons include, among many others, the perceived need to cover a prescribed body of material and the fear of losing classroom control. Many of my colleagues who share these concerns are reluctant to change the way they teach without seeing evidence of greater student achievement (*7*). I have written this article to add to that growing body of evidence.

I have taught the yearlong organic chemistry sequence at California State University, Los Angeles (CSULA), for most of the past 28 years. This class sequence is taken by all biochemistry, biology, chemistry, and microbiology majors and all premedical and predental students. I teach a rigorous course in organic chemistry using essentially only essay exams. The course is heavily mechanistic. I have used *Organic Chemistry*, 4th and 5th editions, by Pine (*8*) as the text for more than 15 years. For the first 23 of my 28 teaching years I taught these classes using the lecture format with many overhead slides and class handouts. During this period I had great success in motivating hundreds of students to study organic chemistry. However, as is the case in many chemistry classes, the attrition rate for my organic classes was very high. From 1983 to 1994, fewer than 50% of the students who began this 3-quarter sequence actually finished the year. (Students must receive a grade of "C" to move on to the next course in the sequence.) I initially assumed that those students who failed to succeed were just not studying enough or were not sufficiently motivated to succeed. Therefore, I tried a number of methods to reach these students, such as expanded office hours and review sessions. These methods always reached a few additional students but not a significant number. About four years ago I reached the conclusion that it was unacceptable for a university professor to fail to educate more than 50% of his students and I decided to do something about it—specifically, to change the way I teach organic chemistry.

Active and Cooperative Learning Results

A number of articles have appeared describing strategies for increasing the retention rate in organic chemistry classes. These include team learning (9), student-directed learning (*10*), learning cycles (*11*), and grade/study-performance contracts (*12*). During the past four years I have introduced cooperative learning, classroom assessment, and active learning into my organic chemistry classes. The results have been astounding. Table 1 shows the courses involved, total sections, average student enrollments, and pass rates for a 15-year period, comparing data using the standard lecture format to data using the new strategies.

One problem with any pedagogical experiment is the choice of the control. Since the teacher's personality is an important factor in any class, using the classes of a different instructor for the control poses problems. In order to maintain an appropriate control I have included in this table only classes I have taught. The pass rate is defined as the total number of A, B, and C grades compared to the total number of students enrolled at the end of the first week of classes, which is the end of our no-record drop period. The pass rate has increased by 21% in the first quarter, 23% in the second quarter, and 10% in the last quarter. Multiplying the three pass rates together provides a retention rate for the entire year of organic chemistry. The lecture method provided an average retention rate of 38% for the year while the cooperative and active-learning strategies provided an average retention rate for the year of 75%. These remarkable results were achieved without decreasing the rigor of exams or lowering grading standards. The exams combine essay questions and mechanistic problems using data from the literature. I have used similar types of exams and similar grading scales throughout the 15-year period reported here. I have served as my own control by including the pass rates in my previous classes in which I did not employ active and cooperative learning.

I have also followed the performance of my lecture students in the laboratory portion of organic chemistry, since the lab and lecture are separate courses. Table 2 compares the performance of students who had an intense active learning

Table 1. A Comparison of the Lecture and Active Learning Formats

Course	Sections (No.)	Av Enrollment	% Pass
Standard Lecture Format: 1984–1994			
Chem 301A	8	48	71 ± 5
Chem 301B	8	50	63 ± 4
Chem 301C	8	40	85 ± 3
Cooperative Learning and Active Learning: 1994–1998			
Chem 301A	3	43	92 ± 2
Chem 301B	3	50	86 ± 4
Chem 301C	4	44	94 ± 2

experience in the organic lecture with that of students who had the more traditional lectures. The first quarter of lecture does not have an associated lab. The 302A lab runs concurrently with Chem 301B lecture and the 302B lab runs concurrently with Chem 301C lecture. The students who had the intense active-learning approach in lecture do significantly better in the laboratory class in terms of both retention and GPA.

Active and Cooperative Learning Strategies

In the following paragraphs I describe the methods I have used for the past four years. CSULA is an urban and ethnically diverse commuter campus with an enrollment of ~19,000 students. In the Fall of 1997 the student body had the following ethnic distribution: 9.6% African-American, 24.4% Asian-American, 48.5% Hispanic, and 17.0% White. A similar diversity is mirrored in my organic classes for the Fall of 1997: 9% African-American, 36% Asian-American, 42% Hispanic, and 13% White. In addition, there is enormous diversity within the Hispanic and Asian-American groupings.

Cooperative Learning Groups

I begin each class by dividing the students into study groups of four students randomized for ethnicity, gender, and GPA in previous chemistry classes. Since many students are initially uncomfortable with my assigning them to groups, I spend about 20 minutes explaining my rationale for the randomized groupings.

One of the major concerns that my industrial chemistry colleagues have about new college graduates is their lack of experience in working as part of a team. This is not surprising: the curve grading system makes students reluctant to study in groups or to assist one other, since the possible number of each grade is limited. In a curve grading system students are competing against each other rather than participating in a learning environment. I now use an absolute grading system so that, theoretically, all students could receive an “A”, but there is also the possibility that no student will receive an “A”. The grading scale is essentially the same one that I have used for years, but I now share it with the students and I do not adjust it up or down as I have done in the past. The class syllabus provides an exact point distribution for each grade. Thus, the students have nothing to lose by helping each other understand course material. Furthermore, this group experience will help them to prepare for the cooperative team nature of many business situations.

I randomize the groups by ethnicity because business and industrial teams are not ethnically segregated. The same argument applies to randomizing the groups by gender. I also randomize the groups by previous chemistry GPA because both high-achieving and average students can benefit from group discussions. High-achieving students will benefit because explaining ideas to others is one of the most effective ways to increase one’s own understanding (*13*). As teachers we have all experienced a situation in which we did not understand some concept very well until we tried to teach it to someone else. Students also develop their listening skills in group discussions. And since English is a second language for many of my students, group work helps them improve their English language skills. The students overwhelmingly indicate on evaluations that they like the group work. I frequently encountered former students of mine who have maintained their study groups in classes where the instructor did not use group activities.

Table 2. A Comparison of Student Performance in Other Classes, Fall 1995–Winter 1998

Organic Lecture Pedagogy	Lab	Students (No.)	Lab Retention (%)	GPA
Intense active learning	302A	109	97	2.73
Predominantly lecture	302A	129	72	2.26
Intense active learning	302B	84	96	2.67
Predominantly lecture	302B	91	86	2.62

Group Activities

I use both in-class and out-of-class group activities. Graded group homework is assigned every week and all group members receive the same grade, which counts for about 10% of the class grade. Group homework problems are either essay questions requiring several paragraphs to answer or rather complicated mechanistic problems. I stress to the students that the logic they use in answering the question is at least as important as the answer. However, it is very important that none of these questions were used in the last few years. When I first started giving group homework I used several problems from a previous year. Invariably, many of the answers to these questions were essentially identical to my answers on the key posted from the previous year.

During each class meeting the students are also given group classwork. The chairs in the room are arranged in semicircular groups of four so that each group can easily interact with me as well as work together as a group. Two or three times in each class period I will give the class a question or problem to discuss in their groups while I circulate around the room listening to their discussions, answering questions, and keeping them on task. After 5 or 10 minutes I open the problem up for class discussion. These can be very lively as the students debate different solutions and approaches to the problem. Several examples of in-class group problems will illustrate this approach.

1. Explain why both acid and base catalysis increases the rate of nucleophilic addition of water to an aldehyde.
2. Why does nucleophilic attack on a protonated carbonyl occur at carbon rather than oxygen?
3. Using your molecular model set, show that the two gauche forms of butane are actually enantiomers.
4. When an electrophile attacks an ester, would you expect the electrophile to add to the carbonyl oxygen or to the alkoxy oxygen?

Student Pre-Class Preparation

Class discussions are much more effective if students have read the assignment for the day. For years I struggled with the problem of more than half of the class not reading the assignment. I now use one-minute blue book quizzes[1] at the beginning of every period. The students bring a blue book to each class meeting. At the beginning of the class I put on the overhead a question that comes from the reading assignment for that period. The question is designed to be easy *if* they have read the assignment. The students have about one minute to answer the question and then the blue books are collected. The total grade for all blue book questions is about

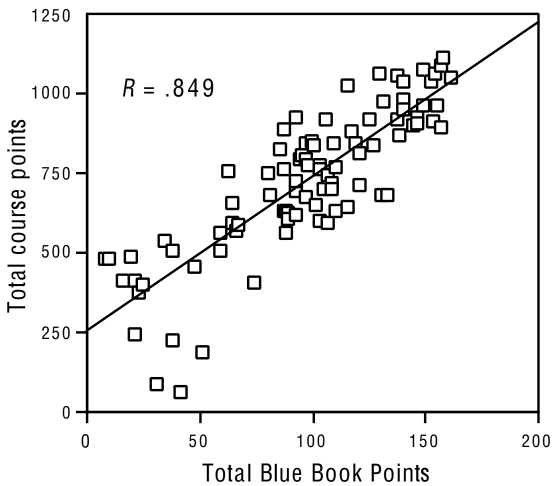

Figure 1. Plot of total number of course points vs total blue book points in Chem 301A and Chem 301B during Fall 1997 and Winter 1998.

10% of the overall grade. This activity accomplishes two things: it encourages the students to read the textbook assignment, and it gets the students to class on time. Each of these is critical if group work in class is to be successful. The students are not fond of the blue book quizzes but they do recognize their value. In Figure 1 the total blue book quiz points are plotted versus the total course points for Fall 1997 (Chem 301A) and Winter 1998 (Chem 301B). The graph shows a close correlation (r = .85). Obviously, many factors other than reading the assignment go into determining a student's grade, but in an active learning situation, reading the course material enables students to get the most out of their classroom experience.

Active Learning Techniques

To make the class a learning experience and not just a source of information, I use a variety of active learning strategies. The group members are numbered so that I can ask, for example, each group member number 2 to explain to the rest of the group a concept that I have just covered. Then I ask each group member number 4 to expand on that explanation. Again, I circulate around the room listening to the explanations and answering questions. It is important that students be able to assess their understanding of the material as it is presented and not just later when they go over their notes.

Finger Signals

I have also found finger signals (*14*) to be very effective both in monitoring student understanding and as a method to elicit student discussion. I use them often. I will pose a question and ask the students to choose among several numbered alternative answers, which are written on the board or displayed on an overhead projector. After allowing time for the students to think about their answer, I ask them to show me their answer by holding the appropriate number of fingers horizontally against their chest. If they can't answer the question, they hold a closed fist next to their chest. This makes it difficult for a student to see how other students have answered the question, but I can easily see what percentage of the class is following my presentation. There are a number of responses one can use after polling the class with finger signals. I sometimes ask for a volunteer to present his or her answer and then ask if anyone wants to expand on or disagree with it. On other occasions I give my answer to the question and invite students who had the right answer to defend it. I usually don't call on students by name to answer these questions, since this inhibits students from answering the question and causes many of them to use the closed fist as their answer.

An example of the use of finger signals would be the following. After we have discussed the acidity of organic molecules, I use two large note cards with A^- written on one and HA written on the other. I hold one in each hand. The distance between the cards represents the relative free energy difference, and the distance of each card from the floor represents the absolute free energy value. I start with the cards in some standard position and then change their positions by moving them up and down at the same time or individually. I ask the students to indicate by finger signals whether the new acid is weaker (one finger), stronger (two fingers), or equal (three fingers) in acidity to the original acid. This provides immediate feedback to me about the students' understanding of the material and requires the students to be actively engaged in thinking about the topic.

The Minute Paper

I also employ the "minute paper" (*15*), in which students are given a few minutes at the end of the class to reflect on a question. The statements are collected but not graded. This is similar to "the muddiest point" concept (*16*) and allows me to assess the class's understanding of the material. Another useful technique is the so-called "fish bowl" (*17*). At the end of the class period each student is given a 3 × 5 card and asked to bring it to the next session with a question about the current topic written on it. As they enter class they drop their unsigned cards into a "fish bowl". I then draw cards out of the bowl and let the class answer the questions. This provides excellent opportunities for discussion.

Class Discussions

Another simple technique works extremely well when students are answering questions in class. Many instructors will rephrase the student's answer to improve it for the class. However, this discourages students from listening to their fellow students' answers because they know the instructor will expand upon the answer anyway. I never repeat a student's answer. I may ask to have it repeated it if the student mumbled or talked softly, but students must listen to their colleague's answer because I won't repeat it. If the student doesn't give an acceptable answer, I ask another question, give the correct question for the answer, or offer hints.

Another important point about class discussions is that each student in the class must "own" the question and actively try to answer it. In many classes the students just wait for the answer to be given and do not think about the problem. The instructor must provide enough "wait-time" after a question to give students an opportunity to think about the question and formulate an answer (*18*). Don't call on a student to answer the question until enough time has been provided. The amount of time required will, of course, depend on the difficulty and complexity of the question. A serious problem is the "blurters" who shout out their answer the minute they have one. This must be prevented if the whole class is to think about the question. Otherwise, students soon realize that they don't need to think about the question because very quickly someone will shout out the answer. I make it quite clear early in the term that shouting out answers is unacceptable.

Breaks and Pauses

Although I am in favor of moving toward greater use of these active and cooperative learning techniques, I am not advocating that we completely abandon the lecture format in the science classroom. It is still one of the best ways to transmit information, even though it does not very effectively promote understanding. Studies have shown that the retention and understanding of material drop off rapidly after about 15–20 minutes of uninterrupted lecture (*19*). Clarification pauses (*20*) are a useful way to break up your lecture. After 10–15 minutes of lecture, circulate among the students while they review their notes. You can see the quality of their notes and answer questions. You can easily check how well they have understood by asking them at the end of the period to write down the most important ideas covered in that day's lecture. I have found this feedback quite revealing.

Another good way to break up the lecture is to ask the students to share their notes and then ask each other questions about them (the "share-pair" technique [*21*]). You can also ask the students to number off as 1 and 2, 1 and 2, …. Then ask number 1 to explain to number 2 a concept that has just been discussed.

Occasionally I write on the blackboard a separate problem for each study group and have the students start to work as soon as they enter the classroom. I circulate among them observing the group dynamics and answering questions. Halfway through the period I have each group select a spokesperson. Then, one at a time, the groups explain their answer. During this time the class is encouraged to ask questions.

Review Sessions

Since I began teaching 28 years ago, I have given weekly review sessions outside of class in which the students ask me questions and I give detailed answers. This didn't seem to help most of the students because they were not engaged in understanding the material but were merely copying down whatever I said. Usually only the better students attended these sessions. For the past two years I have run my review sessions by dividing the students into groups of two or three and then writing a problem on the blackboard. The students are given 15 minutes to work on the problem while I circulate among them. Then I ask them to provide information about how they have begun to solve the problem. I purposely choose problems for which the answer is ambiguous so that students have to think critically to evaluate the problem. I have relied heavily on the ideas of Craig Nelson (*22*) in developing critical thinking strategies. In one problem I provide a series of esters and ask the students to evaluate the pros and cons for each of three or four possible ester hydrolysis mechanisms. The esters are chosen so that it is not clear which mechanism would be the "correct" one. These review sessions resulted in much better scores on exam questions about ester hydrolysis. Also, a good cross section of the class now attends these sessions. The students have responded very well to this new format for review sessions.

Conclusions

The process of changing my classroom from one of lecture to one where active learning and group learning are used was gradual. It is a mistake to go from lecture to active learning overnight. It takes a fair amount of practice and experimentation to learn how to effectively employ active learning in the classroom. The active learning strategies presented above, or any of the other methods discussed in the literature cited, can be slowly incorporated into your teaching style. It is also very important to explain in detail to your students why you are trying the new techniques. Students are much more likely to accept a new style of teaching if they know the reasons behind it. An advantage to using varied teaching methods is the well-known fact that students have different learning styles (*23*).

Implementing even a few of the ideas discussed above will reduce the amount of material that can be "covered". It is important to recognize that in no field of science can one cover all available topics. I would much prefer my students to have a good grasp of fewer topics than to have been deluged with information they will not remember six months later. I was convinced of this several years ago while discussing the basic topic of Lewis structures. I asked my class to generate as many valid Lewis structures as possible for HNO_3. Almost all my students gave only one structure—nitric acid. I soon discovered that they had no idea how to generate Lewis structures even though it had been "covered" in at least three previous chemistry classes. They had merely memorized the structures for many commonly encountered molecules. Rote memorization is the usual fallback for students when the amount of material covered is excessive. This leads to students who do not understand the course material.

In my organic classes I cover the same topics that I have always covered but I do not lecture on introductory material. I assume that the students have read and studied the assignment. I also use fewer examples than I used previously; however, I talk about these examples in greater detail. Thus, even though I am covering less total material, the students are discussing the material at a higher level than would have been possible without active and cooperative learning.

Thanks to the techniques outlined above, my students enjoy organic chemistry more and are able to participate in in-depth discussions of open-ended problems. They can also apply the principles of mechanistic organic chemistry to a much wider range of problems than my former students who received their instruction in a predominantly lecture format. In addition, the retention rate has dramatically increased and the students perform better in the organic laboratory sections.

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Note

1. I want to thank Ken Anderson, Department of Biology and Microbiology, California State University, Los Angeles for suggesting this technique. These quizzes are similar to Reading Quizzes but should not be confused with Conceptests, both of which are described by Mazur (see ref *1*, *Peer Instruction: A User's Manual*, and ref *5*, *Conceptests*).

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