learning, (4) what they did with team-based learning (e.g., including at least one example of a question, problem, or activity they gave to students to work on), and (5) what outcomes team-based learning produced for their students and for themselves.

All in all, we (the editors) were very impressed by the amazing set of ideas and stories they produced. Although each voice is unique in many ways, the overwhelming conclusion one receives from their experiences—taken as a whole—is that team-based learning will work in a wide variety of teaching situations, promotes powerful forms of student learning, and is truly a transforming way of teaching.

Nonetheless a reader might still ask: Why should I read a chapter about teaching that is in a discipline quite different from my own? If I teach accounting, for example, why should I read about how someone teaches chemistry or human relations?

We are quite confident that readers will find that these chapters all have a value that speaks well beyond the particular subject matter involved. If readers approach the chapters in Part II with an open and inquiring mind, they will almost certainly feel the excitement that the teacher and the students felt as a result of this kind of engagement with the material; they will be able to see the results of team-based learning implemented properly in multiple settings; and they will develop a fuller understanding of the principles necessary to make team-based learning work effectively in almost any setting.

Chapter 5

An Alternative to Lecturing in the Sciences

Frank J. Dinan

Despite winning several teaching awards as an outstanding lecturer, Dinan was concerned about continuing problems with poor student performance in his chemistry classes. After attending a workshop and learning about team-based learning, he decided to give it a try. He found the results extremely satisfying: nearly perfect attendance, students coming to class well prepared, a significant reduction in the withdrawal and failure rate, an ability to cover more content, and significantly higher student performance on the final exam.

I first became aware of team-based learning during the summer of 1993 when I attended a case studies workshop conducted by Clyde (Kipp) Herreid. My goal was to learn about the case method of teaching, but I was totally unaware of team-based learning. Late in the workshop, we were told that on the following day we would be doing some work on an active-learning technique called team-based learning, and were given material to be read in preparation for that class. The assigned reading was one of Larry Michaelsen's publications describing the workings of team-based learning, and we were informed that we would have a reading quiz the following morning. So, although I had other plans for that evening, I reluctantly but dutifully read the paper to prepare for the quiz.

In class the following morning we formed groups and set out to answer the questions that Kipp had devised to test our knowledge of team-based learning. I greatly enjoyed working with my team and discussing the details of the method with them. I recall sitting in the workshop reflecting on how engrossing the team work had proven to be, and how the method had caused me to take time to read and prepare for today's class despite my other commitments. It was at that point that it occurred to me that team-based learning could potentially revolutionize the way I taught organic chemistry. My experiences that day led me to see that team-based learning had the potential to deal with many of the problems that today's students encounter in physical science courses taught by the lecture method.

At that time I had taught organic chemistry for twenty-five years at Canisius College. I had won a number of teaching awards, and was generally thought of as a successful teacher. In recent years, however, I had sensed a definite decline in the effectiveness of the lecture method in my courses. Student attendance was not as consistently high as it had been, and, despite my best efforts at "clarifying" the material presented in my lectures, the results on examinations were often disappointing to me. Combined student withdrawal and failure rates were also higher than I found acceptable, about 15 to 20 percent. My response to this situation was to work harder and harder at making my lectures clearer and more entertaining, but nothing that I did seemed to have any positive effect. Although my student evaluations remained good, I suspected that the evaluations may have become a better measure of the effort that I put into making my lectures entertaining than to their effectiveness in teaching organic chemistry. My colleagues' frequent complaints about "today's students" and the disappointingly high student withdrawal and failure rates that characterized their courses indicated that I was not alone in these perceptions.

My misgivings with the traditional lecture method were further enhanced upon reading Sheila Tobias' article, "They're Not Dumb, They're Different" (1990). Tobias documented the disaffection that many capable students feel with the passive role that the lecture method imposes on them in introductory physical science courses. Her work demonstrated that many intelligent students taking lecture-based physical science courses compare their experiences in these courses unfavorably to the more interactive teaching methods frequently used in the social sciences and liberal arts. This comparison, Tobias demonstrated, leads many of these students to desert the physical sciences in large numbers. Because the attrition rate for students majoring in the physical sciences, both at Canisius College and nationally, is very high, Tobias's findings forcefully caught my attention.

At about this same time, the results obtained in a study conducted at Arizona State University (Birk & Foster, 1993), also strongly predisposed me to consider alternative teaching methodologies. This extensive study was carried out over several years, and concentrated on evaluating the effectiveness of the lecture format in teaching chemistry courses. Among the main conclusions drawn were these: (1) the degree of learning that occurs in a chemistry course taught by the lecture method is independent of the lecturer, and (2) attendance at lectures had only a marginal effect on a student's performance in the course.

Together, these findings further undermined my confidence in the adequacy of lecture as an effective teaching method in the natural sciences, and prompted my interest in team-based learning as a potentially more effective teaching methodology. The basic elements of team-based learning seemed well suited to the teaching of chemistry, and I set out to tailor the method to meet the specific needs of my organic chemistry course.

Modifications had to be made to fit team-based learning to the specific demands of teaching organic chemistry, and to fit the situation that exists at Canisius College. Organic classes at Canisius range in size from forty to sixty students, and meet four times per week. Three of these classes are fifty minutes long and are termed lecture periods. The fourth class, a recitation period, is seventy-five minutes long and is used to review problems assigned during the previous several classes. The students taking organic chemistry are mainly sophomores majoring in the physical sciences, usually chemistry, biochemistry, or biology. For the most part, they are bright, highly motivated young people who plan to pursue graduate training in either the physical sciences or some area of the health sciences.

When teaching organic chemistry, it is traditional to rely heavily on the text as a primary information source. Our students are normally urged to read the text carefully, but of course, many do not do so. Often this is true because the professor, during his or her lecture presentation, spends the class time attempting to organize and clarify the text's information for the students. Thus, students who have read the text may find the lecture dull and repetitive, and those who have not done the reading often have difficulty following the condensed lecture's content. So, with these thoughts in mind, I set out to modify Michaelsen's basic team-based learning method to suit it to teaching organic chemistry.

The modified team-based learning method that resulted focuses on the efficient use of small groups in the teaching of high-content subjects, such as organic chemistry and general chemistry, that are typical of the physical sciences. This method utilizes many of the elements of the team-based learning method that Michaelsen originally developed, and the highlights of its operation are described below.

On the first day of class, I announce the composition of the four- or five-person permanent teams in which the students will work for the remainder of the semester. The goal that I seek in structuring the teams is to obtain the maximum possible diversity within the teams in terms of race, gender, and academic ability. To accomplish this, I use student academic performance data, principally grades obtained in previous chemistry courses, to assure that each group will have a wide distribution of academic abilities. My experience indicates that this is a highly effective manner by which to form teams. The variation in race, gender, and academic ability is intended to reflect the experiences that await the students when they enter today's "real world" and to help them to learn to deal with the wide range of people, personalities and abilities that they will surely encounter in that world.

While the newly formed teams are carrying out some get-acquainted exercises—for example, sharing common work experiences, places they have visited, favorite foods, and so on—a photo is taken of each team. The students write their names under their pictures, and indicate what they prefer to be called in class. This allows the instructor to correlate student names and faces very quickly, and facilitates a congenial class atmosphere. The team photos are also circulated throughout the class and posted so that the students can quickly learn each other's names. Additionally, each team is asked to decide on a team name, one that they feel represents some aspect of their collective personalities. These exercises are helpful in building an open, friendly classroom atmosphere, which I have found greatly minimizes student anxiety. Anxiety levels can often be very high at the beginning of any new course, and our experience indicates this can be a debilitating problem for many beginning chemistry students.

On the second day of class, I describe the grading system to be used in the course. I stress that the team-based learning system is designed to reward both individual and group achievement. Working in their groups, the class then decides, within limits set by the instructor, the relative weights they wish to assign to the three components of the grading scheme: group, individual, and peer evaluation grades. The allowed limits are such that the individual component of the grading scheme represents at least three-quarters of each student's grade. This process has proven to be a very effective team-building exercise, and one that shows the students that they have a voice in the equity of the course's operation.

The text used in a chemistry course taught by team-based learning must be clearly written and readable by the students with only occasional assistance. Fortunately, several high-quality organic chemistry texts are available that meet these criteria. I am currently using Solomons and Fryhle's *Organic Chemistry*, 7th Edition (1998). The text is divided into segments that can be covered in one class; normally, this is about one-third of a text chapter. A learning guide is then prepared for each of these single-class segments. The guide specifies exactly how the students are to prepare for a class; it lists the text material to be read, that which is to be omitted, and the specific problems to be done in preparation for the next class. It may also include brief comments about the relative importance of the assigned materials and some of the instructor's tips on dealing with the material in an effective manner. The learning guide for a class is normally distributed to the students at least two days before the class meets.

Each class meeting, except for the recitation classes, is a team-based learning class. The class begins with a reading quiz that is focused on several aspects of the text's content that have been specified in the learning guide. A reading quiz generally consists of three short-answer or multiple-choice questions. It is printed in large, boldface type and is projected for viewing using an overhead projector. Student answers to the reading quizzes may be entered and graded using Scantron sheets or other forms designed for this purpose. Approximately thirty reading quizzes are given over the course of a semester, and the percentage score obtained by each student on these quizzes is counted as one of four hourly examination grades. The entire reading quiz procedure generally consumes less than five minutes of class time.

I have always had an undergraduate student assistant in my organic chemistry team-based learning classes. In recent years this has been a student who has completed this course within the past year or two, one whom I judge has the proper combination of knowledge and personality to help me in my work with the teams. The student assistant grades the collected reading quiz responses while I am reviewing the reading quiz and its answers for the class. Every student assistant that I have had so far has gone on to graduate school in chemistry, and has done an outstanding job on his or her preliminary examinations in organic chemistry. This is an unanticipated, but real, benefit of our team-based learning method.

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I have found that the combined use of reading quizzes and learning guides results in virtually every student arriving in class well prepared. At the suggestion of one of my colleagues, I now allow my students to use the notes that they have prepared while reading the material prescribed in the learning guide during the reading quiz. This practice results in the students taking extensive, careful notes while they are reading the assigned text material. The small investment of time that is required to give reading quizzes greatly leverages the available class time by assuring and rewarding good student preparation for class.

Upon completion of the reading quiz, each of the teams is given a problem set based on the learning guide for that class. A typical problem set, which I call a "ChemDo," consists of three or four problems dealing with the more difficult or problematic material assigned in the learning guide for that class. Although the problems are designed to be challenging for the teams, care must be taken to insure that they are not overwhelmingly difficult. The problems in a ChemDo are also designed to increase in difficulty as the students move through them. For example, a ChemDo might begin by asking the teams to clarify and explain some of the major concepts dealt with in the learning guide. The next question might require applications of these concepts to specific problems, and the ChemDo might conclude with a problem that requires the teams to integrate the material in the current learning guide with previously covered course material. A specific example of ChemDo design follows.

One of the ChemDos that is used in my organic course deals with the concept of aromaticity. It begins by asking the teams to clearly explain and define the meaning of the terms "aromatic," "nonaromatic," and "anti-aromatic." The ChemDo next asks the teams to illustrate how these concepts apply to specific molecules. To do this, the teams are required to use the polygon-and-circle method to determine the number and relative energies of the molecular orbital present in these molecules, and to show how electrons are distributed in each of the molecules. They must then use this information to decide whether each of the example molecules is aromatic, nonaromatic, or anti-aromatic.

At the end of class, each team submits one copy of the ChemDo completed that day for grading. To keep my work at a manageable level, I arbitrarily select only one of the (usually) three ChemDo questions for grading. ChemDos are graded on a one-to-four scale, and the resulting grade is awarded to all of those members of the submitting team that were present in class that day. Note that on missing a class, students must not only explain their absence to their team members, but they also miss the course points that can be gained from the day's reading quiz and ChemDo.

Any ChemDo question or its answer can be challenged by a team if the members feel that they have a sound basis for doing so. A question can be challenged as not being appropriate for the day's learning guide, and any one of my answers to the ChemDo questions can be successfully challenged if the team can support its challenge with a specific reference from the text. The team that has initiated a successful challenge is automatically awarded the maximum grade of four for the ChemDo, plus a bonus point. This practice prompts the students to closely scrutinize each ChemDo's content and the answers that I have given.

Three one-hour examinations are given in each semester of the course. These examinations are taken by individuals first, and then by the teams. To insure individual accountability, individual examination scores are weighted more heavily than are group scores, usually by a ratio of four or five to one. Answers to the examination questions are also subject to the challenge process described earlier.

The combination of daily reading quizzes which, in total, count as an hour examination, and peer pressure to be present to support the team's ChemDo efforts in class, result in nearly perfect attendance. This is a remarkable improvement over the attendance rate that was characteristic of my pre-team-based learning classes when absence rates of ten to fifteen percent were common.

Our experience clearly shows that once a team-based learning class is underway, the teams motivate attendance and preparation for class, and afford learning support to their members. The resulting positive atmosphere builds student connectivity and tends to minimize feelings of alienation and marginality. This may be the single factor that is most responsible for the low attrition rates that characterize these classes. Team-based learning students also quickly come to recognize how important good communication skills and interpersonal relationships are to their success. Most students tend to improve their skills in these areas throughout the course.

Our six years of team-based learning teaching has shown that this method can be very rewarding for the instructor as well. It is a joy to watch as students come to class regularly, arrive on time (usually early), and generally behave as professionals who are responsible for their own learning. Discussions within the learning teams are a pleasure to hear; they quickly focus on the material specified in the learning guide for that class, and are conducted at a high level of intensity. It is very satisfying to watch as a student support community grows and strengthens as the course progresses.

However, even given all of these positive features of our application of team-based learning, the method would be of no real value unless it resulted in effective instruction in the discipline. This aspect of the method has been carefully investigated. Our evaluation of the effectiveness of team-based learning in organic and general chemistry is based on six years of experience with the method, and encompasses both its cognitive and affective dimensions. Some of the conclusions that we have reached are described below.

Quantitative evaluations of our students' attitudes toward their team-based learning experience over a six-year period have afforded the following results:

- 95% of students feel that team-based learning builds better relationships among students than does the lecture method.
- 83% of students feel that team-based learning is a better way to learn organic chemistry than is the lecture method.
- 78% of students feel that team-based learning requires more consistent work than does the lecture method.
- 90% of students feel responsible to prepare for each class as well as possible.

- 93% of students feel responsible to their teams to be present in class everyday.
- Only 16% of students report that they learn chemistry better with the lecture method than they do with team-based learning.

The coverage of content is always a concern in chemistry courses because many of our students will take national qualifying examinations for graduate and professional schools. These examinations assume that the students taking them have been exposed to a wide range of content. Our experience with this team-based learning method has demonstrated that about ten to fifteen percent more course material can be covered using team-based learning than is feasible using the lecture method. It is frequently a problem for an instructor using the lecture method to keep up with another using team-based learning. This, I believe, results from the more thorough preparation for class that team-based learning requires of its students.

A major concern about the effectiveness of team-based learning is how well students learn organic chemistry when using this method. To investigate this question, results obtained on common, objective final examinations taken by both team-based learning and lecture students have been compared. These studies showed that the team-based learning classes consistently obtain statistically significant higher mean and average grades than do the lecture students. Over a period of five years, the team-based learning student performance on comprehensive, objective final examinations has averaged about five percent higher than that of the lecture students. These data are significant at the 95 percent confidence level.

One last consideration favoring team-based learning over the lecture method is student retention. Here, we have found team-based learning to be far superior to lecture. Combined student withdrawal and failure rates due to all causes over the two semesters of organic chemistry lecture courses at Canisius College historically run about 17 percent. The average combined withdrawal and failure rate in team-based learning organic chemistry classes taught over the past six years is less than 5 percent, and in one year was actually zero.

To put the academic performance of team-based learning students versus lecture students on common final examinations in better perspective, the difference in retention rates between lecture and team-based learning classes should be considered. In the latter, due to the higher student retention rates described, students who would have long since withdrawn from a lecture class generally finish the team-based learning class. Therefore, they take the final examination. So team-based learning student performances on the final examinations are actually more impressive than they seem at first glance because many of the academically weaker students in the team-based learning classes do take that examination, while those students often withdraw from lecture classes before taking the final examination. Without this effect, it is reasonable to assume that the difference in performance between team-based learning and lecture classes would be even greater.

I should note that, although I do not normally teach general chemistry, a freshman course, I did do so once four years ago to check the effectiveness of our modified team-based learning method in that introductory level course. The results that I obtained were closely comparable to those that I have described here for the organic chemistry course. A number of the students, now seniors, who were present in that general chemistry class often comment favorably on their experiences in that course whenever we meet. They recall with special fondness the closeness and friendships that developed during that course that still survive today.

In summary, team-based learning is an effective method for teaching introductory level chemistry courses. It is involving, active, effective, and leads to higher student success rates than does the lecture method. It is also highly rewarding to the instructor. The student–instructor relationship is altered remarkably for the better. Instead of functioning as a lecturer and evaluator of the student's learning, the instructor becomes a coach who is part of a team that is there to help smooth out the rough parts on the road leading to their success. This change in role is frequently noted in comments made on student course evaluations, where satisfaction rates consistently run above the 90-percent level.

Based on the experience that we have gained over the past seven years, it seems evident that suitably modified team-based learning courses could also be used very effectively in other introductory-level science and mathematics courses. Student evaluations of their team-based learning chemistry classes strongly indicate they would like to use team-based learning in other science and mathematics courses.

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CHAPTER 6

Using Case Studies in Science—And Still "Covering the Content"

Clyde Freeman Herreid

Many professors worry about shifting to small groups and other forms of active learning because of a fear they will not be able to cover as much content. Herreid used case studies with team-based learning and found his students learned as much or more, and comments on why this was so.

In the summer of 1992, I was invited to come to Vanderbilt University and give a lecture on the art of teaching. They were having a faculty colloquium, an annual event hosted by their Office of Teaching Effectiveness. They had invited me to lecture on how to lecture. I entitled my talk "The Ten Commandments." I am sure they thought they were getting something divinely inspired. Not willing to dissuade them of their fantasy, I went calling.

I gave my presentation to a large and generous audience. Not long afterward, I found myself seated at lunch with another presenter who was scheduled to speak in the afternoon on something called "team-based learning." In our brief exchange I found out that Larry Michaelsen had given up lecturing and was enthralled with a new method of presenting material that was a cross between collaborative learning and mastery teaching. He did not attend my lecture; I suppose it would have been antithetical to his newfound wisdom.

For years I had been looking for alternative forms of teaching, reasoning that I had exhausted the nuances of the lecture method and was ready to move on. I was midcareer and still found many students failing my classes. They complimented me on my presentations, yet there was always an eternal stream of students coming to office hours complaining that they did not understand why they could not absorb the material and