Cooperative Learning in General Chemistry

A Carnegie Scholar Project on Teaching and Learning

Dennis C. Jacobs
Department of Chemistry and Biochemistry
University of Notre Dame
June, 2000

General Chemistry is a challenging and often traumatic experience for first-year students. The introductory course covers a large amount of material at a rapid pace, builds vertically on numerous non-intuitive concepts, and requires students to solve problems they have never encountered before. At the University of Notre Dame, students with Math SAT scores below 640, have historically demonstrated only a 40% success rate for completing one full year of General Chemistry taught in the traditional lecture format. In the Fall of 1997, I developed a new General Chemistry sequence for students identified as being 'at-risk' for performing poorly in General Chemistry. These students are taught the same material as those enrolled in the traditional General Chemistry course, but are given weekly graded homework assignments, quizzes, and mandatory recitation sections in which they collaboratively solve problems in small groups. Active learning, concept integration, creative problem solving, individual accountability, and frequent feedback are central goals in the course design.

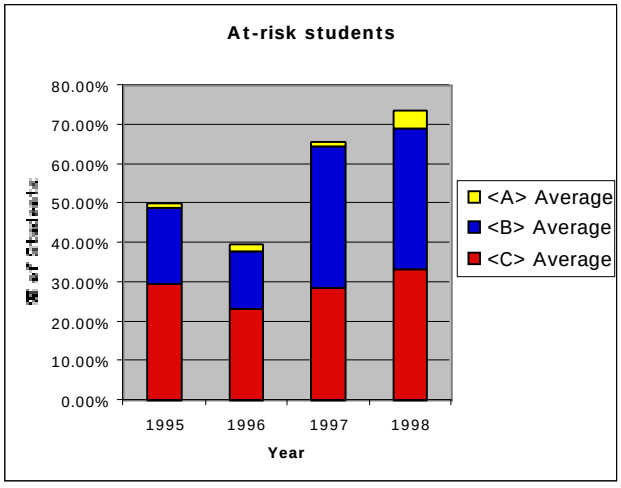
My project as a Carnegie Scholar has been to examine the impact of incorporating cooperative learning strategies in a large section (> 200 'at-risk' students) of General Chemistry. This report is organized around the various lines of inquiry and methodological approaches I have pursued during the past year.

Question: What impact do cooperative learning methods and weekly feedback have on the conceptual understanding, problem-solving ability, and self-confidence developed by students?

Methodological Approach: Test performance data on 4000 students, spanning two years before and two years after intervention; surveys of students who experienced both traditional and alternative course formats.

What I Have Learned:

The percentage of at-risk students who were successful in completing an entire year of General Chemistry with an average grade of C or better rose dramatically after the alternative section was introduced. Figure 1 shows the distribution of outcomes for each of four General Chemistry cohorts. In 1995 and 1996, only the traditional lecture section was offered. In 1997 and 1998, most at-risk students were placed in the alternative section.



The percentage of at-risk students, who were able to achieve a B average or better, doubled with the advent of the alternative course.

Most students continued in the same General Chemistry sequence in which they started. However, some students elected to transfer after one semester from the traditional to the alternative sections, or vice versa. Virtually all students who transferred from the traditional course to the alternative course showed marked improvement. However, those students who transferred in the opposite direction performed at a lower level in the Spring (traditional course) than they did in the Fall (alternative course). Both migrating populations were surveyed to learn more about their relative experiences. Regardless of the order in which students experienced the two course formats, they reported enhanced self-confidence, deeper conceptual understanding, greater interest in Chemistry, and improved problem-solving skills when they were enrolled in the alternative section compared to the traditional section.

Question: What types of test questions do 'at-risk' students find most challenging? Do cooperative learning approaches enhance particular cognitive abilities?
Methodological Approach: Item analysis on test performance data; Taxonomies
What I Have Learned: Students enrolled in the traditional and alternative sections were given a series of identical questions distributed over 20 exams, across four semesters. These common multiple choice questions were representative of the entire range of questions students were asked in the course. The common test problems were sorted into one of the first four categories in Bloom's Taxonomy: Knowledge, Comprehension, Application, and Analysis. Students tended to score higher on questions of the first two types than the latter types. It is generally accepted that Bloom's classifications are listed in order of increasing cognitive demand. Because students in the traditional and alternative courses were taught by different instructors, it was difficult to distinguish which problems should be classified as Comprehension versus Application. Whether a problem is seen as new depends on the precise set of problems a student has experienced in lecture and in homework.

A more objective classification scheme than Bloom's taxonomy is to categorize problems according to how many independent concepts a student must integrate in order to form a complete solution. As expected, students perform better on the problems that require the use of fewer concepts. Tests questions were also classified by the type of chemical knowledge or skill required to solve a given problem. In all of the above classification schemes, the non-at-risk students outperformed the at-risk students. There did not seem to be any particular category in which the 'at-risk' students did much better or much worse than their non-at-risk counterparts.

Question: Under what conditions do students judge their best learning occurs? How do they know when they understand a chemistry concept?
Methodological Approach: Focus Groups and Surveys of students enrolled in both traditional and alternative sections of General Chemistry (Fall, 1999)
What I Have Learned: In general, students enrolled in the traditional course exhibited poor study habits. Most wait until two days prior to a test before they put a

serious effort into studying. Many are heavily reliant on the solution manual for learning recipes for solving representative problems. The survey data indicates that only 28% of the students in the traditional course report that they read the textbook before lecture at least half the time. In contrast, 55% of the students in the alternative section read the textbook before lecture at least half of the time. The survey also indicates that students in the alternative section spend twice as many hours per week studying chemistry as do their counterparts in the traditional section.

The common myth among faculty is that the students who struggle on exams are not working as hard as the successful students. Just the opposite conclusion is garnered from the survey results. Although students with more consistent study patterns score lower than their peers, their test performance is more likely to improve over the course of a semester.

Students in the traditional course judge that their best learning takes place through studying for exams; however, there is no significant correlation between holding this opinion and performing well on exams. For those in the alternative course, students, who believed that doing homework and listening to lecture were useful learning experiences, tended to do better on exams. Non-at-risk students, who believed that understanding the mathematical relationship between things was a good way to learn, did perform better on exams. At-risk students who held this same belief were more likely to improve over the course of a semester. Of the students enrolled in the alternative section, those who valued giving one-on-one explanations did better on the exams.

Question: What design elements of cooperative learning activities are most effective in stimulating meaningful group discussion, promoting deeper conceptual understanding, and developing problem-solving skills?

Methodological Approach: Videotaped small groups in recitation sections; Focus group discussions

What I Have Learned: Videotaping has provided a unique window on the learning process. By capturing small-groups of students solving problems cooperatively, I have been able to observe and describe the types of TA-student and student-student interactions that appear most conducive to learning. The video camera unobtrusively records a small group before, during, and after a TA visits with the group. The TA's choice to intervene in a particular situation can help the group gain insight, save the group from becoming overly frustrated, or it can lead the group down a path of greater dependency on instructor assistance. Focus group discussions around the small-group problem solving experience have revealed that many students feel rushed and are worried about the points their group might be missing. The students want more interaction with the TA. When polled, the students were willing to stay longer to receive this additional assistance. Viewing the videotapes with TAs has promoted discussion about the TA's vital role in establishing an environment where cooperative learning is effective and enjoyable.

Videotaping small groups of students engaged in cooperative learning exercises has also provided invaluable feedback on the types of assigned problems and questions that promote meaningful group discussion. This input aids in the revision and creation of future small group exercises.

Question: Are students more successful in advanced science courses and in their academic majors if they have experienced cooperative learning approaches in their first-year General Chemistry course?

Methodological Approach: Four-year statistics (4000 students) on retention and letter grades earned in advanced courses; GPA and choice of major by semester.

What I Have Learned: Students who scored poorly on the Math SAT exam have historically avoided Science and Engineering to a greater extent than did those who scored above 630 on the Math SAT. However, since introducing an alternative General Chemistry sequence, 50% more 'at-risk' students have majored in Science than in prior years. Retention of 'at-risk' students in sophomore-level organic chemistry and biology courses has also increased 50% since introducing the alternative General Chemistry section. At the same time, average letter grades earned by 'at-risk' students in these advanced courses remain unchanged.

Future Directions:

- The existing data sets can be analyzed in a variety of new ways. For example, what is the relative impact of cooperative learning methods on male versus female students, or on students from different racial or socioeconomic backgrounds?
- This summer, the longitudinal study can be extended out an additional year.
- Additionally, I am working with three faculty in my department on a two-year project to assess the type of learning that takes place in the associated General Chemistry laboratory. Specifically, we will investigate the ways that students transfer information from the classroom to the lab and back again.

Bibliography:

1. Anderson, L. W.; Soniak, L. A. *Bloom's Taxonomy: A Forty-year Retrospective;* Part II, National Society for the Study of Education, Chicago (1994).
2. Bloom, B. S. et al., *Taxonomy of Educational Objectives, The Classification of Educational Goals, Handbook I: Cognitive Domain,* Longman Publishing Group, New York (1956).
3. Grasha, A. F., *Teaching with Style: A practical guide to enhancing learning by understanding teaching and learning styles,* Alliance, Pittsburgh, PA.
4. Krueger, R. A. *Focus Groups: A Practical Guide for Applied Research*; 2nd Edition. Sage Publications, Thousand Oaks, CA (1994).
5. Mazur, Eric *Peer Instruction,* Prentice Hall (1998).
6. Smith, K.A.; Waller, A.A. in *New Paradigms for College Teaching,* Campbell, W. E. and Smith, K.A., Eds., Edina, MN (1997).
7. Springer, L.; Stanne, M. E.; Donovan, S. S.; "Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta Analysis"; *Rev. of Educational Research*, **69**, pp. 21-51 (1999).