Promoting Student Learning through Group Problem Solving in General Chemistry Recitations

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Advancement in science often results from a healthy exchange of ideas among scientists working on similar problems. This collaboration fosters a sense of community among the scientists and is crucial to the development of science. There is ample evidence that students benefit in many ways from collaborative learning as well *(1–7)*. The healthy exchange of ideas within small groups not only increases interest among the participants but also promotes critical thinking. Students working in groups are able to retain information longer as well as think at a higher level *(3)*. The shared learning gives students an opportunity to engage in discussion, take responsibility for their own learning, and become critical thinkers *(4, 6)*. In fact, collaborative learning has been shown to have a positive impact on student attitudes toward chemistry *(8)*. The traditional chemistry lecture, however, does not typically provide students with opportunities to exchange ideas about the material presented, especially if it is a large class (>50 students). Instructors hesitate to adopt collaborative learning methods for a large class, fearing that the time used in promoting effective discussion among students may limit the content covered. Instructors of content-rich courses, such as chemistry, do need to strike a balance between presenting course content and promoting discussion of that content in the classroom. It is possible to achieve this balance as several authors adopting different models of group learning have shown *(7–9)*.

Outside of the traditional lecture, students often seek out peers and work in informal groups, usually groups of friends, to study for exams or solve homework problems. However, this process may not be effective for all students. Not all students choose to work in a group. When such groups form they might frequently involve like-minded students who may take a similar approach to studying the course material and might have the same misconceptions. In addition, such a homogeneous group might not contain the range of perspectives needed to understand new material and might not address common misconceptions.

The general chemistry course at USP is offered to first-year students not majoring in chemistry. The demographics of a typical general chemistry section include students pursuing degrees in pharmacy, physical therapy, biology, and occupational therapy. As part of their program requirements, these majors are all required to take this course. For a number of years, the general chemistry course had four lecture sections with about 90 students in each section. One optional recitation session was offered for each lecture section to provide students with an opportunity to ask questions. Typically, a faculty member would answer questions and work example problems. Since attendance at these sessions was optional, it was typically poor. Many of those who attended these recitation sessions passively copied down the solved problems and therefore did not get the benefit from going through the thought process required to set up solutions to suggested problems. Chemistry as a discipline involves problem solving. A lack of the requisite problem-solving skills in chemistry is an obstruction to doing well in the course. The passive nature of a traditional question-and-answer recitation does not provide an adequate environment to develop these skills.

These challenges prompted a review of the class structure. Faculty teaching loads in hours per faculty member associated with the course were essentially fixed and additional faculty were not available to teach the course. Thus, a change to smaller class size was not possible. Our approach was to supplement the traditional lecture with collaborative learning in recitation, where students were provided the opportunity to interact with students of varied skills and abilities. The purpose of recitation was changed from a forum at which a faculty member would answer questions to a time during which students worked together to solve problems in groups assigned by faculty. Structured groups in which all students were exposed to a range of perspectives were used so that students became aware of their own misconceptions.

To avoid an increase in contact hours for each faculty associated with the course, originally the four lecture sections were collapsed to two lecture sections of about 180 students each with four recitations sections of about 45 students each. This change not only provided an opportunity for better interaction between students and faculty it also slightly decreased the contact hours for each faculty teaching the course from eight hours (6 hours lecture + 2 hours recitation) to seven hours (3 hours lecture + 4 hours recitation) (Table 1). The implementation took place

Table 1. Comparative Class Structure before and after Implementing Group Problem Solving in Recitation Sections

Treatment	Lecture Sections (Students in Each Section)	Recitation Sections (Students in Each Section)	Recitation Attendance	Faculty Resources	Teaching Assistant Resources for Each Section
Before Implementation					
Fall 2001	4 (90)	1 (90)	Optional	8 hours	None
After Implementation					
Fall 2002	2 (180)	4 (45)	Mandatory	7 hours	1 graduate TA
Fall 2003	3 (160–180)	4 (40–45)	Mandatory	7 hours	2 undergraduate TAs

during a period of increasing enrollment in the course and so in the Fall of 2003 an additional faculty member was hired to teach a third section of the course because the increased enrollment had exceeded the original limits.

Implementation of Group Problem Solving in Recitation

Research on peer and collaborative learning shows that students benefit from group work, only if the model adopted is implemented effectively *(10).* It is necessary to ensure that all students participate in order to benefit from group work. Students' perception of small-group learning is largely positive if the small-group learning is successfully implemented *(11).* Grading the work done in recitation and making it a part of the overall grade ensured student attendance and participation.

Attendance and Participation

Because peer interaction is a very important benefit of group work, attendance at recitation was required. In addition to the instructor, teaching assistants (TAs) were assigned to each recitation to help with grading and to serve as facilitators of the problem-solving process. Students in each recitation were placed in groups of four. Mixed-skill ability was created within each group by including students with high, low, and average mathematics SAT scores. Recitation sessions started with a brief question-and-answer period primarily to focus the students' thoughts on the topics addressed in the problem worksheet. Each group was then given a worksheet with problems to be solved and handed in at the end of the session. The groups were responsible for developing solutions to the problems. The instructor and TA did not provide solutions to the problems but did explain the concepts involved or asked questions to direct the students working on the problems.

Problem 1

Consider the facts presented below and work together with other members of your group to solve the problem. Use complete sentences, equations, and drawings to explain your answers.

Two gases are trapped on opposite sides of a moveable piston in a bath at 273 K. When pressure–temperature equilibrium is reached, the volume of gas A is 15.0 L, and the volume of gas B is 10.0 L.

- What conclusion can be drawn concerning the average kinetic energy per mole (units kJ/mol) of gas A and gas B? Explain.
- What conclusion can be drawn concerning the relative number of moles of A and B? Explain.
- If gas A is CH_3CHO and gas B is N_2O, what is the speed of gas A molecules relative to that of gas B molecules? Explain or show your work.

Textbox 1. A sample exercise undertaken by student groups.

Rooms Assigned for Recitation

The type of room utilized for recitation also played an important role in establishing an environment conducive to discussion. Rooms where students could move their seats around to face other students in the group provided the right environment for students to communicate with each other. It was also important for the instructor and TAs to have easy access to each working group to answer questions. We requested that the registrar assign such rooms for chemistry recitations.

Student Preparation for the Activity

In order for the group work to be considered a success, it was important that a majority of the students successfully finish the problem set. This happened only if the students were prepared for the problem set that they received in recitation. To help students come prepared, problems were assigned as homework before the recitation period. These were both end-of-chapter problems and other problems that illustrated the concepts that were to be explored in recitation.

In the first phase of the implementation, homework was collected in recitation and graded. TAs assigned to the recitation graded the homework. Although this approach did get more students to attempt homework problems before coming to recitation, we were not satisfied that all students were actually attempting the problems or that the teaching assistants grading the homework were able to provide the feedback in a timely fashion. Therefore, since Fall 2005, homework was assigned through WebAssign, an online resource that enables instructors to assign end-of-chapter problems from the textbook. The due date for homework was set before the recitation section met; ensuring students had worked on problems before recitation. Students got immediate feedback on the answers submitted so they knew right away if they attempted the problem correctly or not.

Effective Participation of Group Members

In the initial implementation of the group work model, all group members received the same grade. This did create problems as some students felt that they were doing most of the work. In order to encourage all members of a group to become involved, a system of peer-evaluation was implemented. The peer evaluation was modeled after the work reported in the *Journal of Student Centered Learning (13).*

Criteria for the Problem Sets

In order to ensure maximum participation of all group members, it was essential to develop problem sets that promoted discussion among group members. Multi-step problems, problems that cannot be solved from direct application of formulas, and problems that encourage discussion of ideas (estimations, qualitative answers) were used. The problems generally had a higher level of difficulty than standard homework problems. A sample problem set is shown in Textbox 1. Recitation problems differed from the types of problem usually seen on exams (multiple choice) and homework. The recitation problems were intended to stimulate thought and discussion. We employed several strategies to develop such problems. The example given does not specify a particular form for the answer; all three of the questions could be answered quantitatively or qualitatively. The ambiguity will typically start discussion within the group.

Multi-step problems circumvented an approach in which the group simply divided up the work; many of the problems we used are multi-step.

Assessment of the Group Work Model

The general chemistry course was restructured to incorporate group problem solving in recitation in Fall 2002 when one of the faculty teaching general chemistry retired and a new faculty member (MM) was hired. We used the exam scores from the continuing faculty (FS) to determine the effect of the group problem solving on student learning. Learning outcomes in the general chemistry courses were assessed by using multiple-choice exams because of the ease of administering them to the large classes. The same test bank of questions was used both before and after implementation of the group work. The course grades were assigned using the same cut-off for each letter grade before and after implementation.

In the process of analyzing the data for this paper it was observed that for the spring semesters, the average scores and grade distributions for each section were affected by the scheduling of courses in other departments. Due to scheduling conflicts, the students repeating biology had a conflict with one section of chemistry. When spring semester scores were examined, the section without the repeat biology students was observed to have a higher average than the other sections. The section affected was not consistent year to year since the repeat biology course was rescheduled each year. Given the complications associated with the individual spring semester averages the authors decided to evaluate the impact of the implementation using only fall semester data for FS's sections. For the semesters prior to the implementation the data from the two sections taught by FS are combined; both sections took the same examinations. After the implementation, FS taught only one section.

The most significant result of implementation of the group work was a decrease in the percentage of students receiving less than a 60% average on exams, from 27.5% to about 19% (Table 2). The grade distributions on exams before and after implementation are shown in Figure 1. We believe that the lower percentage of A, B, and C grades in Fall 2002 in comparison to Fall 2003 could be due to several factors. Because it was the first year of implementation, several aspects of the model were found to hamper group interaction and were not used in subsequent years. The model adopted initially included roles for individual students within a group. Adhering to the roles required enough effort from the students that it was considered to be an impediment to group interaction, so roles within the group was discarded. Another aspect of the original model was a reorganization of groups at mid-semester. This was found to disrupt group dynamics that developed in the first half of the semester. Reestablishing the dynamics took several weeks.

The two-sample t-test was performed on the exam averages for FS's sections, before and after the group work was introduced, to see whether there were differences in the averages due to the implementation of the group work. The results are presented in Table 3. The two-sample t-test for Fall 2000–Fall 2001 indicated that the averages for Fall 2000 and Fall 2001 are not significantly different. A similar comparison for Fall 2001–Fall 2002 data

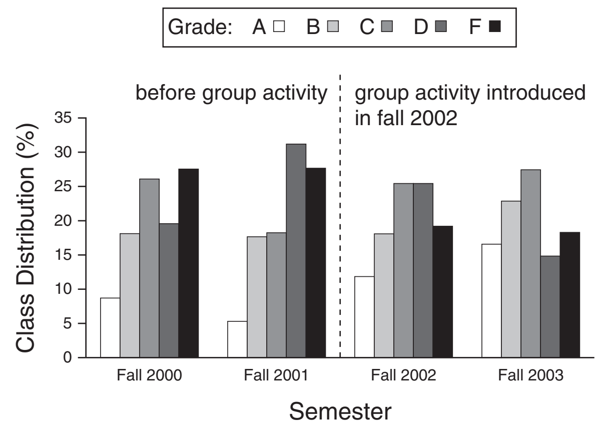

Figure 1. Distribution of letter grades before and after implementation of group problem solving. Group problem solving was introduced in Fall 2002.

Table 2. Distribution of Students Averaging Less Than 60% on Exams, before and after Implementation of the Group Work

Treatment Groups	Class Size (Sections)	Students with Exam Averages below 60% (%)
Before		
Fall 2000	138 (2)	27.54
Fall 2001	170 (2)	27.65
After		
Fall 2002	175 (1)	19.21
Fall 2003	177 (1)	18.29

Table 3. Statistical Comparison of Students' Exam Scores before and after Implementation of the Group Problem Solving Exercises

Treatment Groups	Class Size	Average SAT Mathematics Score	Average Exam Score	Median Exam Score	p-Values (Two-Sample t-Test)	p-Values (Mann–Whitney Test)
Before						
Fall 2000	138	562	69.5	71.0	0.2521	0.1670
Fall 2001	170	568	67.5	66.9	0.2521	0.1670
After						
Fall 2001	170	568	67.5	66.9	0.004617	0.003306
Fall 2002	175	571	71.7	71.8	0.004617	0.003306

suggested an improvement in the average. The nonparametric Mann–Whitney test that compares the median for the two semesters also indicated no significant difference in the median values for Fall 2000 and Fall 2001. A comparison of median scores for Fall 2001 and Fall 2002 suggested an improvement in the median score for the Fall 2002 data.

We considered the possible influence of better-prepared entering first-year students by looking at the mathematics SAT scores of the students. The data suggested that the approximately 10% increase in A, B, C, and D grades could not have come from the modest increase in the average SAT scores (568 in Fall 2001 versus 571 in Fall 2002).

Student Responses

Surveys administered at mid-semester and near the end of the semester indicated a positive student response; group work was generally viewed as helpful. Contrary to expectation, very few students complained about the mandatory recitation.

Typical student reactions to the recitation were:

> Recitation helps students grow and improve their skills by working in groups. Each group member usually grasps a concept a different way; therefore if someone did not understand the material, they had many opportunities to learn and understand from their group members' feedback. Recitation also helps students gain points to help raise their grade if they struggled on exams or lecture prep quizzes. The recitation is a useful tool for preparing for exams and learning concepts!

> I think it was a good idea to pick the groups at random so that friends do not gather and then some people will do all of the work and some will just socialize. The problems related to the material that was being taught in lecture. There should be a little more time to go over the homework problems, or maybe like a problem that everyone works on together as a class to begin the recitation might work.

> Although working in groups allows one to see other approaches to working on problems, there are also some downfalls. In my group there were numerous times when two of the members would show up without any of the assigned problems done. This created trouble when we were trying to solve the problem sets since they did not know how to properly solve the problems. Being able to interact one on one with the professor and TAs was a great feature of recitation.

Effective Implementation of the Group Work Model

During the course of the six years since the original implementation of the group work model we have identified several factors that impact the effectiveness of the group work model.

1. Class size is an important factor. Classes that have more than 45–48 students are hampered significantly from the reduced interactions between the groups and the instructor and TAs. Twelve groups of four students seem to be the limit for effective implementation of the group work. Though groups of three and five have been used, smaller groups usually lack the diversity of thought and larger groups do not allow for full participation among all members *(12)*. Disparate recitation section sizes should be avoided; practical aspects of conducting recitation sections that include group work change with the class size.
2. Having the right number of TAs along with the instructor to provide enough supervision for the classroom ensures all groups are on task. For a class with twelve groups it is important to have at least two TAs. Undergraduates who have experienced the group work model themselves are more effective TAs than graduate students. Graduate students were used in the first year as TAs but now only undergraduates are used as TAs.
3. Issues among students within a group must be identified early in the semester and groups rearranged for minimum disruption.
4. It is important that students come prepared to recitation by attempting the assigned homework problems so that they have sufficient background knowledge to carry on a discussion. To facilitate this, homework problems must be assigned and due prior to recitation.
5. Effective participation of all the group members is essential for all group members to benefit from the activity. A system of peer- and self-evaluation helps towards this goal.

Summary and Conclusions

The students quickly realized that they benefited most from the problem-solving sessions in recitation if they came prepared by doing assigned problems and keeping up with the material presented in the lecture. The mandatory attendance in recitation ensured maximum student participation and forced students to adopt more regular study habits. Students used other resources available, such as tutors, and made better use of office hours to get their assigned questions done before recitation. Therefore, an added bonus of this approach is an increased level of responsibility and a better study ethic adopted by the students—increased quality time on task.

Students generally like working in groups to solve problems. Peer interaction and peer instruction are effective tools for learning, and are good motivators as well. To interact with peers effectively in order to solve a problem, students need to verbalize concepts and problem solving strategies. This is a more effective learning tool than memorization and drill. Good students achieve a higher level of understanding by communicating their ideas while students needing help get their questions answered by a peer who is often viewed as less intimidating. Students learn that chemistry problems are solved through logical thinking, and that simply reading a chapter or memorizing its content does not result in problem solving ability.

Instructors benefit from watching the students and listening in on their discussions. This provides a great opportunity for the instructors to identify and correct misconceptions. Instructors also benefit from getting to know students better, as the recitations are smaller, and therefore provide a better setting for student–instructor interaction.

The main impediment to introducing group work is usually large class size. We have shown that it is possible to enhance student learning by restructuring the course very modestly to include structured group work in addition to the traditional lectures provided by the instructors. Overall, the group interactions seemed to benefit the average to above-average students.

Therefore, the model of using recitation sessions in general chemistry to solve problems in small groups is an effective tool to enhance problem-solving skills in chemistry.

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Supplement
Sample problems for group work on these topics: chemical formulas, specific heat and calorimetry, and the photoelectric effect