Design, Implementation, and Evaluation of Novel Discussion Exercises for First-Year Chemistry Students

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Abstract: In the Fall of 1999, Illinois State University (ISU) piloted a new General Chemistry I course. This course now includes cooperative learning exercises that were developed and implemented in biweekly discussion sections over the past four semesters. We now have discussion exercises all taught by six different tenured and tenure-track faculty members. This study focuses on the effect on student behaviors and learning in General Chemistry I. Data were obtained from student surveys, student interviews, instructor feedback, and examination results. The results obtained in this study show that student interest in chemistry can be maintained or increased by the incorporation of cooperative learning into the general chemistry curriculum. In addition, this cooperative learning approach promoted attendance, was enjoyable for many students, and seemed to have some positive effect on achievement.

Introduction

ISU is a public university located in Normal, Illinois, with an enrollment of approximately 20,000 students. To qualify for admission to ISU, incoming freshman must have a minimum composite ACT score of 17 or SAT score of 830. Prior to 1999, General Chemistry I was a five-credit-hour course consisting of four lectures and one homework review session per week. To comply with American Chemical Society accreditation guidelines, the ISU Chemistry Department chose to add a wet-laboratory experience, reduce the number of lectures per week, and to change the homework review sessions. Part of the motivation for this change was the poor attendance at the homework sessions. The revised General Chemistry I meets three times a week for lecture and once every other week for a three-hour laboratory. In the intervening week the students meet with a faculty member or instructor for a discussion section. This four-hour course serves a variety of clientele. In the Fall of 1999, 36% of the 289 students enrolled in General Chemistry I were biological science majors, 18% of the students were general studies majors, 14% were applied computer science majors, and 8% were chemistry majors. Six faculty members and one graduate student taught the eleven discussion sections in the Fall of 1999. None of the discussion sections contained more than 28 students and, with the exception of one honors section, students were randomly distributed among the other 10 sections.

The two chemistry faculty members and graduate student (we) involved in the modification of this course shared the opinion that students learn best by doing and that certain lecture content could be taught more effectively through cooperative learning exercises. We agreed that the existing discussion sessions, in which instructors reviewed homework problems and administered weekly quizzes, were not maximizing student learning because the students were not being engaged. Moreover, we hoped that incorporating cooperative learning into the discussion sessions might also help to change the negative attitude some students have toward chemistry. Many students are averse to chemistry because they doubt their ability to comprehend it or they do not see the relevance it has to their lives [1]. Cooper [2] and several others [3–9] have found that the advantages of cooperative learning for students in large-enrollment courses are active involvement and personal responsibility, development of higher-level thinking skills, increased content retention, improved attitude toward the subject matter, and satisfaction with the learning experience. For these reasons, our goal in modifying the General Chemistry I recitation was to devise cooperative learning exercises that would increase students' participation in the learning process, which in turn would likely increase their understanding and retention of what they learn, while simultaneously stimulating their interest.

Exercise Considerations and Development

In previous studies of cooperative learning in general chemistry; the authors of the study were also the instructors in charge of the cooperative learning. For instance, Moog, Farrell and Spencer [10], Kogut [5], and Francisco, Nicoll, and Trautmann [3] described implementations of cooperative learning in their own classrooms with 25, 40, and 95 students, respectively. At University of Tennessee, Knoxville, a similar-sized institution to ISU, Kovac coordinated the graduate teaching assistants who taught the cooperative learning discussion of 25 students [6]. In all these cases the authors either controlled their own classroom or were supervisors of the people who did. At ISU, the cooperative learning exercises are implemented in sections of comparable size; however, the instructors of these sections are primarily (90%) tenured and tenure-track faculty. In his study, Kovac [6] comments that teaching assistants adapted well to the cooperative learning

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approach and seemed to enjoy the new mode of teaching. Because no change in pedagogical approach could have been implemented without the consent of our instructors, we were sensitive to the instructor's individuality. We hoped that not only would students gain more from this type of instruction, but that instructors would find this a more gratifying way of teaching.

Others who have studied effective cooperative learning situations provided guidance in three areas. First, students participating in a study of small-group learning conducted by Towns, Kreke, and Fields [11] felt that out-of-class activities diminished the power of working in a group; hence, the exercises were designed to be completed entirely (with little time pressure) during the 2.5-hour discussion period. Second, each student was required to complete a written student guide for each recitation exercise that counted for a minor portion, six percent, of the student's overall course grade. This requirement was included to ensure some individual participation and accountability in the endeavor [2]. In addition, the student guides were graded for completeness in an effort to promote cooperation and diminish competition [4, 6]. Third, we encouraged the instructors to simultaneously encourage student interactions and refrain from interfering in student discussions. As Bodner explained, in cooperative learning "the role of the instructor shifts from 'someone who teaches' to 'someone who facilitates learning'" [12].

Facilitating the exercises required the faculty instructors to adopt a new, flexible teaching style. In particular, the exercises required specific yet flexible instructions so that the faculty would know what they needed to accomplish, yet have the freedom to modify delivery and content of the exercises. The success of cooperative learning depends upon the instructors' enthusiasm for the approach. For example, Dougherty et al. [9] found that students' attitudes toward science and enjoyment of a general chemistry course were most directly influenced by the students' opinion of the instructor. We felt that if the instructors were unsure of what they were supposed to do or felt overly burdened with preparations, their dismay was likely to manifest itself to their students. In conjunction with this, there needed to be a way for the instructors to evaluate what the students learned during an exercise without encumbering the instructors with substantial grading; therefore, the needs of the instructors came second only to the needs of the students in developing the exercises. To address these instructor issues in implementing the exercises, the committee decided that the instructors should be given a detailed guide for each exercise at least a week prior to the scheduled exercise. These instructor's guides provided detailed background information and instructions to minimize the instructor's preparation time; however, it was made explicitly clear to the instructors that they could modify the exercises within the parameters of the cooperative learning approaches as long as they covered the discussion material.

In addition to the issues already mentioned, other logistical considerations influenced the development of the exercises, including coordination with the lecture, exercise length, and classroom facilities. Coordinating the 11 discussion sections over a two-week period meant that students would be exposed to different amounts of lecture material prior to participating in the exercises. This scheduling challenge required flexibility as sometimes students required background knowledge not yet covered in the lecture nor in the exercise. Similarly, determining the length of time needed to complete all of the exercise's objectives was a major consideration. We designed the exercises so that they could be completed within a 1.5-to-2-hour class period to maximize student and instructor participation and attention. Finally, the discussion sections met in classrooms with individual desks, a whiteboard, an overhead projector, and a TV/VCR, but no laboratory or demonstration facilities. As a result the exercises involved paper handouts, molecular models, videos, and some solid crystals.

Discussion Exercises

Table 1 lists the discussion exercises and their content and a brief summary of the activities.

Research Methods

Using both qualitative and quantitative methods we investigated the influence of the discussion exercises on student attitude and learning in General Chemistry I. The effectiveness of the exercises in achieving our goals—maximizing student performance and interest in chemistry through cooperative learning—was measured using written surveys, oral interviews, feedback from faculty instructors, and examination results.

When surveyed, students were asked both content and attitude questions. Students selfreported how well the exercise improved their understanding of a concept, how interesting they found the exercise, and what they liked and disliked about it. Other questions pertaining to the instructional materials and methods used in the exercise were included in these surveys as well. Some questions required a Likert scale rating from one to five, whereas others were posed in an open-ended fashion. Students were surveyed at three specific times in the semester: immediately after each exercise, one week after each exercise, and at the end of the semester; however, to avoid overkill and lack of enthusiasm for survey completion, at the completion of each exercise, only two of eleven sections were surveyed. Hence, each student only responded to three surveys during the semester. For assessing content knowledge, students were asked to solve problems on the surveys using concepts from the discussion exercises. Students were also evaluated for content understanding using multiple-choice questions on monthly and final examinations.

Personal interviews were conducted with faculty instructors throughout the semester. All instructors provided feedback in three formal meetings at the beginning, middle, and end of the semester. Feedback was also frequently elicited from the instructors during informal hallway "bump-ins." Instructors were asked about such things as the difficulties they experienced leading the exercises, common misconceptions students had, and how the students approached an exercise. Personal interviews with students were conducted at the end of the semester with volunteers recruited from the lecture portion of the course. These students were representative of the class in that they came from a broad range of backgrounds, including community college transfers students, an honors student, a General Chemistry I repeater, and an Armed Forces veteran; most of these students were biology majors. Their commentary helped us to understand much of the survey data we obtained.

Table 1. Exercise Topics

Exercise Content	Activity
1. The Crash of Flight 143 Units, Dimensional Analysis, Significant Figures	Students read an article and try to decipher why the refueling calculation was in error.
2. Nomenclature of Everyday Chemicals[a] Naming Ionic and Covalent Compounds, Uses of Common Chemicals	Students are provided with the basic nomenclature rules and are then asked to name a variety of everyday chemicals and their uses are briefly discussed.
3. The Allotropes of Carbon Allotropes, Microscopic and Macroscopic Properties, Process of Scientific Discovery	Students are asked to evaluate the three major allotropes of C and describe their physical properties. Students watch part of a NOVA video on the discovery of C_{60} and then try to decide who should be awarded the Nobel Prize.
4. Alien Periodic Table Periodic Trends, Reactivity	Students are given a series of Alien elements and must arrange them based upon chemical and physical properties.
5. Crystals[b] Chemistry of Gemstones, Unit Cells	Students are divided into groups based upon birth month and then answer questions from information provided on their birthstone and their three dimensional structure.
6. Lewis Structures Drawing Lewis Structures, Molecular Shape	Using VSEPR and the octet rule students derive 2-D and pseudo-3-D shapes for molecules.
7. Gases Gas Laws and Practical Applications	Students are given a diagram of either a refrigerator, or an air conditioner, or a hot air balloon, or a gas furnace; and, using their text, are asked to make a presentation to their discussion group on the gas laws involved.

[a] For student and instructor guide hyperlinks, see ref 13. [b] For student and instructor guide hyperlinks, see ref 14.

Results and Analysis

In comparison to the pre-1999 homework review sessions, the cooperative learning exercises in the discussion sections have had a direct effect on actively engaging the students in the learning process. In the pre-1999 homework review sessions, attendance was rarely higher than 75%. In the new General Chemistry I discussion sections, attendance averages are over 90%. The increase in participation in the discussion sessions indicates that students are taking a more active role in learning and can see the direct benefits of the cooperative learning exercises.

In addition to improved attendance, student performance on content portions of quizzes and examinations is the same or better in the revised General Chemistry I program for those topics that are covered in discussion sections, and their retention of the course material appeared to be high as shown by the students' performance on monthly and final examination questions. For example, in the Fall 1999 end-of-semester survey, 58% of the students rated the Lewis Structures exercise the most beneficial exercise to their performance in the course. During the semester 51% of the students answered the Lewis Structures question on the midterm examination correctly, while 62% answered a similar question correctly on the final examination, indicating that the students retained their knowledge over the semester period. Overall, the averages of the mid-term and final examination scores for the old and revised General Chemistry I course were the same; however, a direct comparison with the "old" course is not valid due to other changes made in the program.

On the end-of-semester whole-class survey, 60% of the students said they had an interest in chemistry prior to taking the course, 14% said they were disinterested, and the remaining 26% said they were neutral. This question was followed by another that asked students to rate the influence the cooperative learning exercises had on their attitude about chemistry—decreased interest, no impact, or increased interest. The data reveals that for the majority of the students who began the course already interested in chemistry (the original 60%) the cooperative learning exercises either increased their interest even more or maintained it. The cooperative learning exercises also improved or had no effect on most of the students who were neutral or disinterested at the beginning of the course (the original 26%). For most of the students who were disinterested in chemistry prior to this course (the original 14%), the cooperative learning exercises did little to increase their interest. Overall, however, we were very pleased that the cooperative learning exercises improved the interest of 41% of the students across all three groups and maintained the interest of another 44%, but we also would have liked to improve the interest of the other 15% of the students. To put these results into perspective, we also asked students about the effect of laboratory and lecture on their interest level. Initially interested and neutral students responded similarly to the laboratory portion of the course by improving the initially interested students' interest and having little impact upon the neutral students; however, initially disinterested students reported laboratory as improving their interest.

Several factors, such as discussion topics, discussion length, effectiveness of group work, instructor enthusiasm, and the amount of time spent going over homework, might influence a student's feelings about the discussion sections, which, in turn, might affect the student's perception of chemistry in general. To understand the effect of these, students were asked whether they liked, disliked, or had no opinion about the discussions, which primarily consisted of the cooperative learning exercises in the end-of-semester survey (50% of the students liked, 28% disliked, and 22% had no opinion). This survey item was linked to another question that asked students to cite the primary reason for their initial answer.

Figure 1 shows the results for those students who liked and disliked the discussion sessions. The main reasons that students liked the sessions were the cooperative approach (group work), discussion topics, and instructor enthusiasm. The primary reason that students disliked the cooperative learning exercises was because of the length of time, which we determined from the student interviews was specifically due to the fact that they felt that they were too lengthy. When the factors influencing the students' opinions of the discussion sessions were broken down by section it was evident that each section was populated

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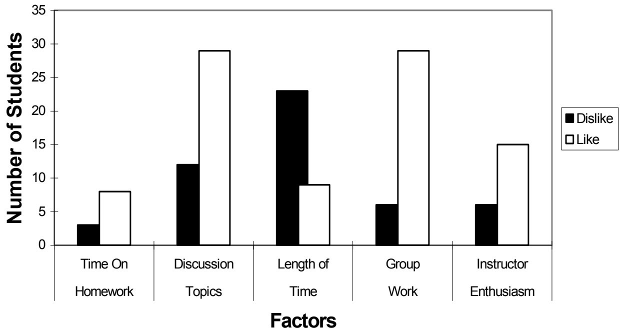

Figure 1. Factors influencing student opinion of discussion sessions based on cooperative learning exercises.

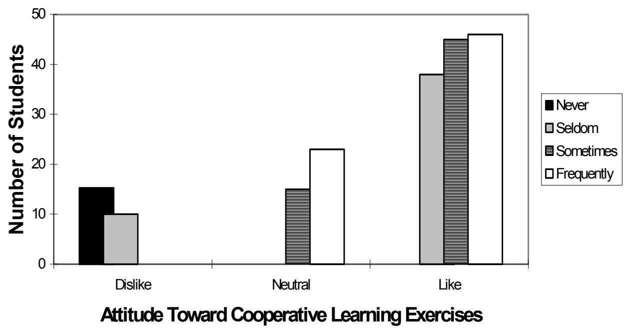

Figure 2. Correlation between attitude toward cooperative learning exercises and frequency of effectiveness of group work.

by students who valued different aspects of the experience. These results mirror those obtained by Dougherty and coworkers [9] and further demonstrate that the success of a program depends upon more than just the content of the program; it also relies on the instructor's commitment to the program, excitement about what they are teaching, and individual teaching style. Like Dougherty, we believe that instructors play the second most important role in any classroom and that in particular, in a co-operative learning environment, that the attitude and skill of the instructor is vital for success as a co-operative activity. What is interesting to note is that this issue is almost completely transparent in the General Chemistry I program, that is, students did *not* notice that their instructors were either particularly enthusiastic or unenthusiastic about co-operative learning. The focus of the students' responses was on the length of time available, the topic at hand, or the co-operative nature of the activity itself. This is a tremendously important result in that it indicates that tenured and tenure-track faculty can and will embrace co-operative learning to the extent that their students will focus on the learning of content and not upon the nature of their instructor's abilities.

We were specifically interested in determining if students benefited from group work; therefore, students were asked on the end-of-semester survey how often their understanding was increased as a result of interactions with other members of their group (24% said frequently, 42% said sometimes, 21% said seldom, and 13% said never). Figure 2 reveals a pattern between a student's attitude toward the discussion sessions and how effective the student viewed group work (Figure 2). The vast majority of the students that liked discussion both enjoyed the experience and felt they frequently or sometimes learned something through the group interactions. Alternatively, students who did not like discussion reported that they seldom or never learned something when working in groups.

Students who were interviewed were asked to describe their experiences with cooperative learning. Even though most students claimed that they were biased against group work coming into the course, the consensus of these students was that cooperative learning works extremely well when all members of the group participate, but it works poorly when some members are apathetic and withdrawn.

- When everybody wants to get involved it's awesome to see what other people think and you didn't think about…. So I think when you get in a group and its functioning good [sic], it's awesome.
- I just don't like group things. I never have. It's something that I have to work on because I'm always going to have to work in a group. I either figure it out myself and then I'm explaining it to other people or they figure it out and I'm copying the answers.
- I personally like to do things individually, and I always have so it makes it hard for me to say that I like group sessions. I don't know if I pick the bad group or get into groups where nobody wants to participate and they all sit around. And that's frustrating.

Because two-thirds of the students that responded to the end-of-semester survey said that they sometimes or frequently learned something through group interactions, it seems that cooperative learning has promise for success in this setting. From the above dialogue of students who were interviewed in-depth, however, it is also clear that, under the current discussion design, individual success is not dependent enough on group success to drive students to work together.

In the end of year surveys and personal interviews, students identified the relevancy of chemistry brought forth in the discussion exercises, as well as the variety of learning experiences, as being particularly helpful in learning chemistry and promoting their interest in the subject.

- The discussions are good because they take you away from constantly just learning that one little thing. … It shows you why you are learning things. So you don't feel like your time is wasted or you're like, "What am I learning all this for?" If you are a biology major, that's like one of your big questions. And then when you have the discussions, it gives you reasons for learning it.
- I felt that discussion was a good addition. Learning about real-life applications of chemistry added some interest to the course.
- I think discussion part should be part of any chemistry class for it makes chemistry more fun!
- I think the way the lecture/discussion/labs were set up was very beneficial in helping me understand chemistry. It was nice to not just sit in a lecture.

The use of phrases such as "daily life," "real life," and "makes chemistry more fun!" indicates that the discussion exercises address some of the problems cited by Gillespie, such as too much theory, lack of orientation to nonchemistry majors, and the relevance of principles in students' lives [15].

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Conclusion

In summary, the inclusion of these seven cooperative learning exercises was an improvement over the previous General Chemistry I homework review sessions and has become an integral part of the General Chemistry program. The current General Chemistry I coordinator and the tenured and tenure-track faculty instructors are continually modifying and developing the discussion section activities; however, no one is considering dropping the cooperative learning approach from the course. Part of the reason for this commitment may be the first-hand experience that the faculty instructors have with increased student interest, attendance, and a positive effect on achievement.

While this cooperative learning approach promoted attendance and retention, was enjoyable for many students, and seemed to have some positive effect on achievement, it could still be improved to bring about more of the positive outcomes of cooperative learning. Cooper and others [2–9] indicated that in addition to these effects, we might also promote active involvement, personal responsibility, and the development of higher-level thinking skills; however, further study or refinement of exercises will be needed to identify the presence of these effects.

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Supporting Materials. The Student Survey for the module "Nomenclature of Everyday Chemicals" and the end-of-semester student survey are available as supporting materials (http://dx.doi.org/10.1007/s00897000626b)

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