Effects of an Active Learning Environment: Teaching Innovations at a Research I Institution

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Literature and research clearly address the need to change the way chemistry is taught, particularly at the introductory level. During the early part of the 20th century, curricular changes in the general chemistry curriculum addressed course content, and these changes were easily accepted since they involved updating topics discussed. Educational reports over the past three decades strongly suggest the need for change in methods of instruction and evaluation as focus has shifted to the way students learn *(1)*. In 1989, a National Science Foundation task force was created to review and evaluate the general chemistry curriculum. One of the directions recommended by the Task Force for General Chemistry Curriculum was to reorganize the course around the laboratory via a laboratory-centered curriculum *(2)*. Focusing on laboratory instruction demands close examination of how well lecture topics and lab experiences relate. The efficacy of this connection is in question since research on laboratory instruction indicates that students cannot interpret their data and observations within the context of chemical concepts discussed in lecture *(3)*. A comprehensive review article on laboratory instruction also shows that labs have little measurable effect on the educational achievement of students *(4)*. In addition, the article points out how different laboratory activities result in very different learning outcomes and that these differences demand rigorous studies of the effects of laboratory teaching and learning.

This paper describes a new approach for teaching general chemistry that combines lecture and laboratory into one seamless session and incorporates instructional methods supported by research-based findings. Students enrolled in this class were compared to students in a conventional lecture-based class. The objective of this study was to compare differences in student understanding of basic chemical concepts and effective use of higher-order cognitive skills by students exposed to the two different instructional formats. The results of the study are also presented.

Program Description

A new approach for teaching general chemistry entitled "concept Advancement through chemistry Lab–Lecture", $cAcL_2$, fully integrates lab and lecture components of introductory chemistry—students no longer attend a separate laboratory for this course. In this integrated format, lecture is minimized while time devoted to hands-on, student-centered activities is maximized. In a typical two-hour session, two short lectures of 15–20 minutes are interjected between activities.

Activity tasks include modified versions of all traditional labs currently performed by students enrolled in a conventional section of this general chemistry course.

This program is a dissemination project of SCALE-UP, Student-Centered Activities for Large Enrollment-Undergraduate Programs. SCALE-UP originated in the Physics Department at North Carolina State University *(5)*. In this format an active environment is promoted by classroom management techniques, classroom design, and collaborative work while technology is incorporated into all three areas. Chemistry, physics, and mathematics departments at several institutions have combined efforts to adopt the SCALE-UP format; $cAcL_2$ is the resulting program developed for chemistry at North Carolina State University. For the implementation of $cAcL_2$, all chemistry activities were developed for use in the SCALE-UP classroom using SCALE-UP management techniques.

Classroom Design and Management Techniques

A special room houses SCALE-UP courses at NCSU. The room holds up to 99 students who are divided in teams of three seated at 11 round tables. Round tables were chosen to promote collaboration among team members as well as among the group of three teams. A laptop with Internet access is provided for every team. White boards around the entire room are readily accessible to all teams. Computer technology and multimedia projectors in conjunction with screens at both ends of the room are used to ensure visibility for all students. A picture of the current room design with the integrated technology is shown in Figure 1.

Figure 1. The SCALE-UP room at North Carolina State University.

In order to manage an active class of up to 99 students effectively, certain classroom management techniques are essential. First, all students have name cards placed in front of them to help both instructors and students establish a sense of community and facilitate communication. All tables are numbered to facilitate collection and distribution of papers. Electronic homework is due every class period but other group or individual assignments can be collected by the roll of a die. A special 12-sided die is used to determine which table(s) will hand in their assignment. This requires all 99 students to be responsible for doing their assignments but grading can be reduced to a fraction of the student population. A quick evaluation of team comprehension can be assessed by scanning answers that team members write on the white boards. Each of the aforementioned techniques encourages individual accountability, positive interdependence, development of interpersonal and communication skills, as well as effective use of time to make an active class of 99 students relatively easy to manage.

Classroom Dynamics

Establishing a highly collaborative environment is an important goal in $cAcL_2$. Various researchers have reported the necessity and success of cooperative grouping in the classroom *(6–8)*, and specifically in the chemistry classroom *(9)*. Research on collaborative work in SCALE-UP physics classes has indicated optimal conditions when students are placed in teams of three and each team is part of a larger group of nine students per table *(5, 10, 11)*. Grouping arrangements are closely monitored for effectiveness. Team effectiveness is assessed using peer evaluations and test grades. In order to promote the collaborative effort, bonus points are added to the exam scores when teams average above a specified minimum on an exam. This seems to encourage better students to help group members who may be struggling with the material, while slower students tend to show a deeper sense of

responsibility *(5)*. Cooperative grouping techniques are also implemented when groups are formed by the instructor to ensure heterogeneous ability as well as to place at least two women or minority students (male or female) on the same team *(11,12)*.

Curriculum Development

Hands-on activities are used to present content material, allowing students to reason through data and observations. Several factors are considered in the development of these activities, including chemical handling, implementation of microscale techniques, and incorporation of technology. Every activity developed has been written in a specific format to guide instructors as facilitators of class work. An outline of a blank activity form and explanation of components is provided in Figure 2.

Demonstrations, labs, and problems found in the literature have been modified and implemented in accordance to $cAcL_2$ guidelines. Demonstrations once performed by the instructor are performed by students in $cAcL_2$ with proper adjustments to scale of quantities and equipment to make it feasible for all. If demonstration conditions call for instructor experience then worksheets are used to guide student learning and keep them mentally engaged in observing and explaining the chemical phenomena being demonstrated. Modifications to existing labs include re-writing procedures to move from verification or "cookbook" labs to more inquiry-guided methods.

Research in specific areas of chemical education reveals common misconceptions that students hold. An extensive project entitled "Student Preconceptions and Misconceptions in Chemistry" is an effort to compile a comprehensive list of the misconceptions in chemistry *(13).* This research has been used to design activities for $cAcL_2$ that intercept or prevent misunderstanding about chemistry. Misconceptions on a particular topic are explicitly stated in each activity.

Title of the Activity

Time:	(Length of time suggested for completing the activity)
Topic:	(Topics covered by this activity)
Type:	(Probe or investigation)
Level:	(Introductory, intermediate, or advanced)
Overview:	(Statement outlining the activity)
Materials and Equipment:	(Items needed to complete the activity)
Objective(s):	(Statements identifying the intended learning outcomes)
Misconceptions:	(Common misunderstandings that conflict with scientific theory)
Other Student Difficulties:	(Areas that should be given special attention)
Prerequisites:	(Concepts or material needed to complete the activity)
Activity Table:	(Outlines every step of the activity for instructors)
Task	(Action to be taken by students or instructors)
Reason	(Why the action is important)
Notes	(Helpful information for instructors)
Related Activities:	(Activities that incorporate related concepts)
References:	(The resources used in developing the activity)
Supplementary Material:	(Discussion of concepts; explanation of demos and procedures)

Figure 2. Activity form used in this general chemistry course taught with the $cAcL_2$ approach.

Incorporation of Technology

The use of computers in education has been both praised and criticized *(14, 15),* but when used in ways that reach beyond a mere display medium, technology can greatly enhance student understanding of chemical concepts *(16–18).* Technology in the $cAcL_2$ classroom is incorporated through the use of computers and projection tools. Every laptop has Internet access, basic software such as Microsoft Excel, Word, and Powerpoint, and special chemistry-related programs, like WebLab Viewer Lite.[1] An instructor station equipped with a camera projector displays material onto two screens located at both ends of the room. This camera can also be directed to the white boards that surround the room so that student displays can be shared with the entire class. In $cAcL_2$, computers are used in five major areas: class management, electronic homework, data collection, graphical analysis, and simulations and animations.

The class materials and notes are organized, managed, and distributed using WebCT.[2] Daily electronic homework is assigned through WebAssign.[3] When combined with chemical probes the computers can be used to collect data that can, in turn, be analyzed through graphical representation. Graphical skills are promoted by requiring students to prepare and interpret graphs of their data. The Internet provides access to many simulations and animations that involve recreating historical experiments or offer tools for students to study chemical behavior. These simulations use student controlled parameters that allow students to perform experiments on the computer. There have been 20 Web sites accessed for first semester $cAcL_2$ activities and over 20 others used as resources.

Experimental Design

This study involved two class sections of the same course taught by the same instructor (MTOH) using two different formats. The course constituted the first semester of a two-semester sequence of general chemistry (CH 101), a required course for all science students. This course is conceptually driven where no algorithmic problems are assigned in class. The lab incorporates basic mathematical manipulations. One class section was conducted in a conventional large lecture setting following a primarily passive format. The second class section was taught in the SCALE-UP classroom designed to promote collaborative work in an active format. Students in both classes signed consent forms agreeing to participate in the research study and allow all materials and results of the study to be disseminated.

Both sections took place during the fall of 2001 and both met during mid-afternoon hours. The passive, conventional lecture class met twice a week for 75 minutes per lecture. Students also enrolled in a separate lab (3 hours per lab) and separate problem session (1 hour per session). Students attended either a problem session or a lab session each week so problem sessions and labs alternated every week. The lecture had seven corresponding lab sections and problem sessions with the same TA conducting a particular section. The active $cAcL_2$ class met three times a week for 100 minutes each time. No separate lab or problem session was required. One TA was assigned to the $cAcL_2$ course and was available during each class. A second TA helped with activity preparation

and grading. Contact hours between instructor and students were closely monitored so that the contact time was comparable in both classes.

Since the same instructor taught the two sections, both content knowledge and time on task were carefully coordinated. The instructional materials used in class covered the same topics with the same perspective and emphasis given to each topic. The difference lay in the delivery format. For example, in the conventional lecture section, the activity series was introduced using demonstrations of reactivity in HCl as well as through various demonstrations comparing reactivity of metals with different cations. The order of reactivity was determined one metal at a time and a table was constructed by the instructor with little student involvement. In the $cAcL_2$ section, students constructed their own activity series by first interacting with four sets of simulated reactions *(19)* and then predicting activity placement of a metal after a live demonstration. Another example of how the same material was covered differently in both classes is the topic of atomic theory regarding principles for electronic configurations and orbital filling. The topics of the Pauli exclusion principle, Hund's Rule, the Aufbau Principle, and ground versus excited states were discussed in the conventional section making use of a hotel analogy using passive lecture methods only. Hotel, apartment, house shape, and house address have all been used as analogies to describe filling orders and orbitals *(20–23).* In $cAcL_2$, these same topics were covered using worksheets discussing the guest logs and occupant filling rules of an "Atomic Hotel". Students completed the four-page worksheet and answered a series of questions involving trends and observations that could be made about hotel characteristics. The worksheet was briefly discussed to ensure all groups had appropriate answers. No lecture was used to relay information for these topics in the $cAcL_2$ section.

Time spent on each topic in class was also carefully controlled. In developing the topic schedule, the time spent on each topic during lecture time, lab experiment time, and problem sessions were added up to determine the allowable time on task dedicated to the same topic in the active format. During the entire semester, the $cAcL_2$ class met for 73.3 hours while the conventional class met for 65.5 hours, including lecture, lab, and problem sessions. The time difference was spent mostly at the beginning of the semester on organizational issues. Examples of issues inherent only to the $cAcL_2$ class include orientation to collaborative techniques, familiarization with the technology to be used in class, and student evaluations of group members.

Syllabi for both sections included a very detailed schedule of the material to be discussed in each class period, exams, suggested readings, and problems. The same homework and example problems were given to both sections. Questions included in activities for the $cAcL_2$ class were also given to students in lecture.

Assessment

In this study assessment of students' performance was conducted using pre- and post-surveys and identical test questions. The pre- and post-surveys used in this study were based on an assessment instrument developed by faculty at Grinnell College and U.C. Berkley with slight modifications *(24).*

1. Use Le Châtelier's Principle to describe what is occurring in the following picture. Be concise in your answer *(25).*

   $$3 H_2 (g) + N_2 (g) \leftrightarrow 2 NH_3 (g)$$
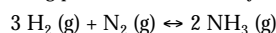
   Required skills for problem 1
   Students must use equilibria criteria to evaluate the relevance of the stoichiometric amounts represented in each picture; changes that the system has been exposed to; and results of these changes. Students must also organize their thoughts to express their conclusions in a concise manner.
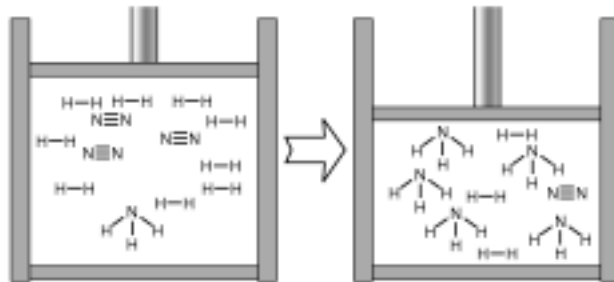
2. A grandmother lived in a rural area of the country noted for its limestone deposits (limestone is $CaCO_3$). She often commented about the "hard water" that she got from her well as a result of the limestone (hard water contains the positive ions Ca^{2+}, Mg^{2+}, and Fe^{2+}). She suffered from swollen ankles and would often soak her feet in Epsom salts (Epsom salts contain $MgSO_4$). One day her granddaughter came to visit her. The grandmother asked the granddaughter to fix a solution of soaking salts so she could soak her swollen feet. The granddaughter was quick to help her grandmother out, but the granddaughter mistakenly poured NaCl instead of $MgSO_4$ in the pan of water assuming that was the "soaking salts" her grandmother requested. After 10 minutes the grandmother was ready for the soaking, but as soon as she saw the solution in the pan she knew her granddaughter had made a mistake. Since Epsom salts and table salt are both soluble in water, how did the grandmother know?[5]

   Required skills for problem 2
   Students must organize the information provided, relate this information to solubility rules, and apply solubility rules to the problem.
   Note: Solubility rules were provided on every test. No memorization was required.

3. Why will a spark ignite a coal dust explosion in a mine and not cause charcoal to react explosively in a barbecue? Give a one-sentence response.
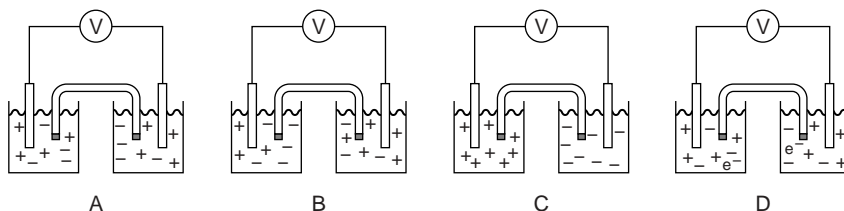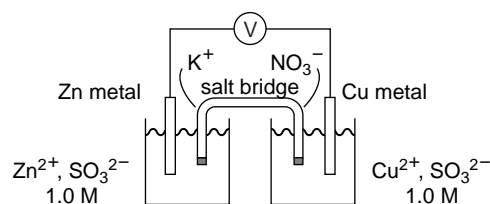
   Required skills for problem 3
   Students must apply information (effects of state of matter and subdivision on chemical reaction rates) to a real-world example.

4. The electrochemical cell shown at right has 1.10 volts for its emf. There is an oxidation reaction and a reduction reaction. Which one(s) of the diagrams below depict each half-cell as the reactions proceed? Explain your answer.
   Note: In the following diagrams, cations are symbolized as + and anions as −. An electron is symbolized as e− *(26).*

   A   B   C   D

   (a) B only   (b) C only   (c) A only   (d) Either A or B   (e) D only

   Required skills for problem 4
   Students need to gather electrochemistry concepts discussed in class and put these ideas together to visualize the progress of the reaction.

5. The unstable fulminate ion (CNO−) has two possible resonance structures *(27).* Circle the best structure and explain your reasoning for that choice.

   $$[\ddot{C}=N=\ddot{O}]^- \longleftrightarrow [C\equiv N-\ddot{O}]^-$$
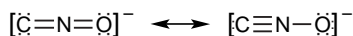
   Required skills for problem 5
   Students must evaluate these examples in terms of Lewis structure guidelines and resonance concepts in order to decide which structure is more reasonable.
   Note: Credit was given based on the reasoning put into elucidation of the best structure.

Figure 3. Examples of questions that promote higher-order cognitive skills.

These surveys were administered electronically to both sections during the first and last two weeks of classes. The pre-survey addressed student background, expectations, study habits, computer skills, and anxiety towards chemistry classes, evaluations, and laboratories. During the last two weeks of classes students were given the opportunity to fill out a post-survey that followed up on the questions given in the pre-survey. The follow-up questions were specifically directed to record changes in attitude brought about by student participation in the course. All attitudinal aspects of this study will be reported in a future article.

Since these sections did not share a common-hour exam schedule, exams were not identical. Exams were very similar in format, length, and amount of material covered per exam. A selected group of questions was designated for both classes and constituted the database for the assessment of exam scores. These questions were carefully chosen and constructed to satisfy the use of higher-order skills such as application, analysis, synthesis, and evaluation.[4] Students must show their work and be explicit in their answers to these specific questions to receive credit. Examples of these questions are given in Figure 3.

In order to maintain consistency in grading, detailed guidelines were given to the TAs and a single TA would grade the same set of questions. To verify grading uniformity, all identical questions were reviewed by a second grader. A total of 64 of these questions were administered to both classes throughout the four exams given during the semester. This set of questions given to both classes was used to obtain adjusted exam scores. An adjusted exam score was obtained by finding the ratio of points attained in challenging questions to total possible value and standardizing to 100%. The statistical analysis of adjusted scores obtained on these questions by students in the passive versus active formats is discussed in the statistical analysis section.

Statistical Analysis

Categorization of Classes

In order to minimize the possibility that a random unidentifiable variable dictated the effects observed in these groups, the equivalency of comparison groups must be established (28).

The measures used to establish similarities between the two comparison groups were academic major and number of previous chemistry courses. Equivalency between the two comparison groups in this study is reflected in the distribution of students in each class per category. Figures 4 and 5 show categorization by these two measures. Demographic pie charts for each class were almost identical; the percentages of each academic major were within 1% of each other. This indicates that there is no confounding effect between field of study and instructional method and that the two class populations are similar. The percentages reflecting previous chemistry courses were within 4% of each other. Since there are no apparent confounding effects, any tests for class effect resulting from our statistical analysis can be considered valid.

Practical Considerations

Prior to running the statistical analysis on any of the data, the data were screened. There were gaps in the data where some students did not take all four exams or did not complete both surveys. Therefore, only complete sets of data where students had taken all four tests and completed both surveys were used in the statistical analysis. Completion of surveys was not mandatory. Students that did not complete all exams were typically students who dropped the course in the first few weeks of the semester. This scenario was found in both classes and was not attributed to the method of teaching. Out of an enrollment of 51 students in the $cAcL_2$ and 150 in the traditional classes 48 students in the $cAcL_2$ section and 119 students in the traditional lecture section met the completed data criteria.

Attention to details was a priority during the planning and scheduling stages of this study. All exams were given to both classes one week after coverage of material was attained with the exception of Exam 3. Due to university holidays and breaks, the conventional class took Exam 3 one week after all material was covered in class while the $cAcL_2$ class took their third exam two weeks after the material was discussed in class. This is the only exam in which scheduling could not be controlled.
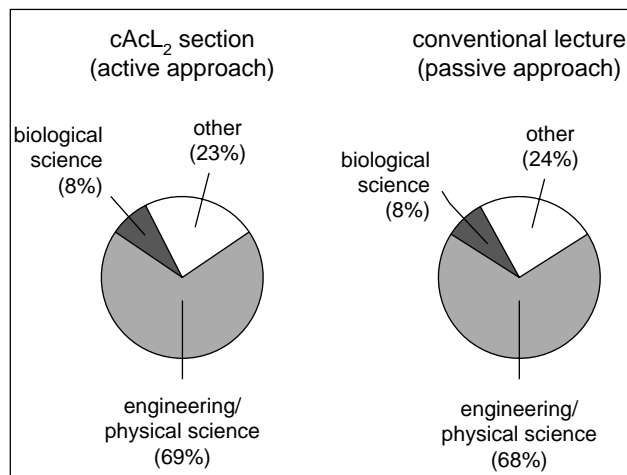

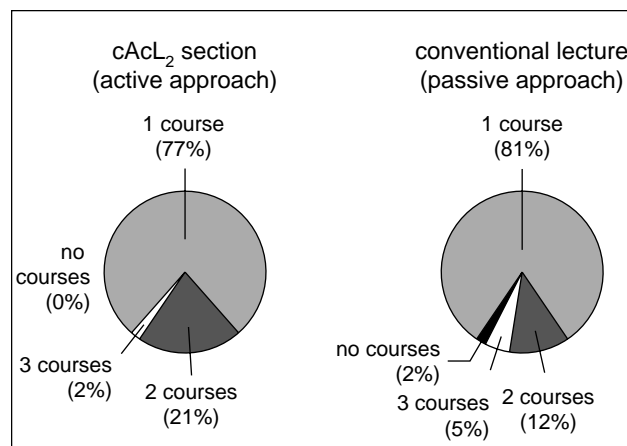Figure 4. Equivalency of comparison groups by academic major.

Figure 5. Equivalency of comparison groups by previous number of chemistry courses taken.

Analysis of variance (ANOVA) was used to answer the question of whether instructional method affects overall student performance. The ANOVA allowed us to take into account other sources of variation besides instructional method (class) such as student major, exam, and any two- and three-way interactions when testing for the class effect. An interaction between class and major exists if the performance of students across the various majors in the conventional instruction differs from the performance of students across the various majors in the $cAcL_2$ section. The following analyses consider adjusted exam scores for each student. These scores were calculated using only the percentage of points earned on the identical questions for each exam.

Model and Assumptions

The data were analyzed using a three-way ANOVA model including terms for class, major, exam, and all two- and three-way interactions. These three factors can be considered to be the major sources of variation in student overall performance. For this model to be valid, exam scores across individuals must be statistically independent, and the exam scores within each individual must be statistically independent. Test scores across individuals are logically independent because knowledge about one student's exam scores gives us no information about another student's test performance. Furthermore, each exam has totally different questions (e.g.,

questions on the first exam will not also appear on another exam). Previous concepts are used within new test questions, but the focus of subsequent test questions is different. Thus, we can say that exam scores for an individual are approximately statistically independent.

The ANOVA model also requires that the students represent a random sample. The descriptive listing for the active class in university records stated that the $cAcL_2$ class was a SCALE-UP section. This is how the university system marks the science courses that have the lab component integrated with the instruction. This course (CH 101) is a requisite for all science majors and is comprised predominantly of freshmen. During the fall semesters, all incoming freshmen receive a predetermined schedule from the registrar's office. Changes are allowed but rarely pursued by freshmen in their first semester in college. Most students do not know what the term SCALE-UP means until the first week of classes when this new format is discussed in class. Thus, students would not pick which section they wanted to be in based on the instructional method. These reasons allow us to confidently consider the two classes to be random samples.

Results of the ANOVA indicated that the exam*major and exam*major*class interactions were not significant. Elimination of these terms resulted in a reduced model that was used to analyze whether students in the $cAcL_2$ section performed better than students in the conventional lecture.

Reduced MODEL
$$y_{ijkl} = \mu + C_i + M_j + E_k + (C^*M)_{ij} + (C^*E)_{ik} + \varepsilon_{ijkl}$$

The SAS output for the reduced model is given in Table 1.

Interpretation of Results

We were interested in testing whether instructional method has an effect on student performance. At an $\alpha = 0.05$ significance level, class is not significant ($p = 0.1012$). This test is performed by taking averages across exams for each class. However, we notice that the exam*class interaction ($p = 0.0428$) is significant, suggesting that we need to compare class performances for each exam instead of across all exams. For each exam we tested the hypothesis that the average performance of the $cAcL_2$ section (μ_2) was higher than the average performance of the conventional instruction section (μ_1): $H_0: \mu_1 = \mu_2$ and $H_a: \mu_2 > \mu_1$. We reject the null hypothesis, H_0, if $t > t_{crit}$ where the critical t value is 1.645. Sample means are used to estimate population means (μ). Table 2 gives the results of this test.

We can conclude at an $\alpha = 0.05$ significance level that the students in the $cAcL_2$ section performed significantly better on average than the students in the conventional lecture section on Exams 2 and 4, while there was no positive significant difference in their performance on Exams 1 and 3. Visualization of the above data is easily achieved by representing the data using boxplots. Schematic boxplots show percentiles, mean, and median values. The "body" of the boxplot represents the interquartile range (IQR), which comprises the 25th percentile (lower end) to 75th percentile (upper end) scores. The "+" sign represents the mean and the crossing line the median. The top 25th percentile extends through a line up to the maximum observation (upper bar) within the upper fence and the lower 25th percentile extends to the minimum observation (lower bar) within the lower fence.

Table 1. Statistical Analysis System (SAS) Modified Output of the Reduced Model

Source	DF	Mean Square	F Value	Pr > F (*p*-value)
Model	11	27687.5473	8.28	<.0001
Exam	3	3292.83156	10.83	<.0001
Major	2	5229.46498	17.20	<.0001
Class	1	819.22303	2.69	0.1012
Exam*class	3	1772.84479	3.17	0.0428
Major*class	2	962.84479	5.83	0.0006

Table 2. Averages, Standard Deviations, and *t*-Test Results for Each Adjusted Exam Score

Exam	Means (Passive Approach)	Means (Active Approach)	Difference in Means, Active vs. Passive	*t*-Value
1	63.4 (19.8)	57.6 (22.5)	-5.8	-1.9
2	65.4 (13.9)	72.0 (12.8)	6.6	2.2
3	58.5 (18.2)	55.6 (19.1)	-2.8	-0.9
4	57.0 (18.8)	66.1 (18.2)	9.1	3.0

As seen in Figure 6, Exam 1 is the only exam in which the passive format class shows higher scores for the bottom 25% of the student population, higher scores for the top 25% of the student population, and a higher average and median. These results came as no surprise due primarily to the exposure to a completely different format during the first few weeks of classes. Adjustments to this class format were obvious as shown by the results for Exam 2. For Exam 2, the $cAcL_2$ class outperformed the passive class in the top and bottom 25%, average, and median values. By the end of the semester, Exam 4 shows that the $cAcL_2$ class achieved significantly higher median and average scores, with the lower 25% of the students also attaining higher scores.

Conclusions

Significant statistical differences between the two sections exposed to different formats, conventional versus $cAcL_2$, suggest that the active instructional method influenced the learning experience of students. For example, the statistical analysis showed that the bottom 25% of the student population in the $cAcL_2$ class outperformed the equivalent population in the conventional lecture in the last three out of the four exams. In addition, the conventional class obtained a higher mean in the first exam, but this difference was reduced on Exam 3 and completely reversed for Exams 2 and 4 where data from $cAcL_2$ students showed higher means than the conventional section.

Recommendations for Future Research

In this paper we discussed the effect of the $cAcL_2$ active learning environment on student performance. For future studies similar to this one, we make these recommendations.

- Provide the same number of similar questions on each exam to allow for longitudinal studies.
- Offer more than one active and passive class to be involved in the study, with multiple instructors participating.
- Replicate the study to check for reproducibility of results.
- Conduct the study with an equal number of students in each class. This would convincingly remove any potential confounding effect associated to class size.

Research on effect of class size points out the predominant issues of student-to-instructor ratio, opportunities for attention, and active involvement in smaller versus larger classes *(29, 30)*, as well as size of working groups *(31)*. In this study the student-to-instructor ratio is obviously different, although the ratio of student-to-TA is actually better for the conventional class (22:1) than for the $cAcL_2$ class (50:1). The classroom design and classroom management techniques used in the $cAcL_2$ format promote an active environment and the effect of class size would have to be studied separately, not necessarily comparing a conventional passive format to an active format. Questions such as, "Are students more likely to ask questions in $cAcL_2$?" or "Do students learn better if they are in smaller classes?" may not be answered justly by comparing two different formats.

Acknowledgments
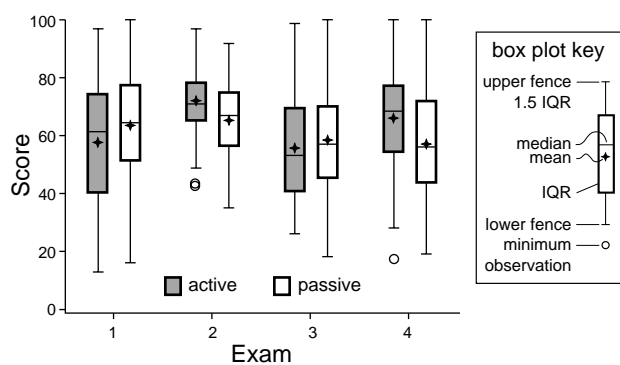
Figure 6. Schematic boxplots for data from active ($cAcL_2$) and passive (conventional) class formats.

Notes

1. See *http://www.accelrys.com/dstudio/ds_viewer/* (accessed Nov 2003).
2. See *http://www.webct.com/* (accessed Nov 2003).
3. See *http://www.webassign.com/* (accessed Nov 2003).
4. Multiple versions of Bloom's taxonomy appear in the literature based on *Taxonomy of Educational Objectives*, Bloom, B., Ed.; David McKay : New York, 1956.
5. Question developed by Kay Sandberg of the chemistry department at North Carolina State University.

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