Design and Implementation of a Studio-Based General Chemistry Course

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Many important questions drive reform-minded instructional development in higher education. During such a limited encounter as one college course, can students learn the scientific-reasoning skills they need to succeed in their careers? Can students equip themselves to make informed decisions that will have far reaching consequences for their lives and the lives of others? How can we engage students, both to improve learning and to make chemistry an exciting challenge rather than impossible? Are our teaching methods best suited to address the ever-growing age, social, and ethnic diversity of our student populations? Can improving instruction attract inquisitive and bright young people to the sciences?

In designing the studio-based general chemistry course, our primary goal was to create a "value-added" chemistry experience by enhancing students' scientific literacy and critical-thinking skills, appreciation and understanding of the scientific method, and ability to apply their chemical knowledge to assessing real-world problems. In pursuit of this goal, we did not want to negatively affect the traditional learning measures in the course by making these other gains at the expense of things such as exam scores. An increase in traditional measures would always be welcomed; however, we were not targeting this as a goal. Although there is precedence to support the hypothesis that we would not be seeing wholesale shifts in exam performance, we were committed to demonstrate that our value-added format could legitimately be classified as a "first, do no harm" format. To these ends, we have two major assessment goals: first, to pursue measures that tap into the anticipated "value-added" aspects of the format and second, to compare traditional measures between students in the value-added course and students in the regular course.

How Can Teaching and Learning Be Improved?

One characteristic of our profession is that good scientific research is informed, intentional, reviewed, and applauded when excellence and utility are demonstrated and then seamlessly adapted in the research laboratories. So too should the results from good educational research be applauded and adapted in the science classroom *(1)*. The National Science Foundation (NSF), seeking specifically to improve undergraduate chemistry education through integration of "good practices", invested in five systemic reform initiatives during the 1990s. These projects *(2–5)* have attempted to package good practices in materials or methods that can be easily adapted or adopted *(6)* in the traditional chemistry curriculum. Other efforts targeted at improving chemistry education include a focus on active learning *(7–9),* more specifically on guided inquiry *(10–13)* and cooperative learning *(14, 15).*

Although many have tried to work within the confines of traditional lab and lecture times, St. Edward's University (Austin, TX) has set aside the traditional class structure and uses two 4-hour lab periods so that students are able to "act as scientists and learn as a scientist learns" *(16).* The University of North Carolina, Charlotte's *(17)* inquiry-based "intimately meshed" lecture and lab and North Carolina State University's *(18)* active-learning environment are other examples. Four chemistry departments, California Polytechnic State University, San Luis Obispo (Cal Poly) *(19),* Rensselaer Polytechnic Institute (RPI) *(20),* California State University, Fullerton *(21),* and the State University of West Georgia *(22)* have adopted the so-called "studio-teaching" approach.

Studio Chemistry Course

In describing this work, "we" refers to an 8-membered team of two faculty (BPC, MMBH), a postdoctoral associate (ACG), four chemistry students (RDS, JMB, JAH, graduate students; ICS, an undergraduate), and a graduate student in education (BPR) who represent our department's model for doing instructional development work by engaging students from all levels who are interested in future academic careers *(23).* Members of the design team conducted site visits at both Cal Poly and RPI in advance of the initial planning in order to better appreciate the implementation efforts of our colleagues in their home institutional settings.

We wanted our students to "act as scientists and learn as a scientist learns", a process that we hypothesize to be more difficult to achieve in independent, highly structured, and segmented lecture and laboratory, the structure that currently exists for general chemistry. The enormous appeal of a chemistry studio is to be able to spend more time in a flexible space where testing hypotheses through research, discussion, and experimentation could be readily carried out. This translated to increased use of laboratory space where a variety of materials and proper safety measures can be made available as well as smaller class sizes for easier management and increased student interactions among peers and course staff.

Our conception of studio chemistry stretches beyond the physical space and becomes an instructional philosophy where the basic learning modes are structured to mimic, with added supporting structures, the research settings where chemistry is practiced, in particular, the research group: providing for meaningful interaction with peers (other members of the research group) as well as structured guidance from experts (senior group members and the research advisor). Student

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chemists not only analyze the work of other chemists and scientists, but their work becomes subject to their critical-thinking analysis and a source of application of their chemical knowledge as well as peer review.

Building the Studio Course

Our four primary *goals* for studio general chemistry are to

- Create an interactive environment for students to gain conceptual and algorithmic *chemical knowledge* through observation, interpretation, and construction of meaning from chemical phenomena (scientific literacy)
- Assist students in creating an *integrated understanding* of chemical principles by relating these principles to other disciplines through a variety of media and to applying their understanding to new situations (creativity; critical thinking and application to real-world examples)
- Insist students experience the *scientific process* of discovery through design and implementation of their own research ideas (scientific method)
- Build a scientific *learning community* based on open discussion and peer critique

A rational pedagogical design requires *structures* that provide organization and help to achieve the course goals. The pedagogical principles we chose are (i) *learning cycles (11, 24, 25)* to ensure active learning, (ii) *guided inquiry* to incorporate creativity and discovery by bringing individual talents to bear on chemical learning and to accomplish scientific research, and (iii) *cooperative learning (26, 27)* to promote the scientific community *(28, 29).*

We chose four *components* to meet our goals in the studio course:

- Studios: twice-weekly blocks in an interactive environment for students to observe, interpret, and construct chemical phenomena
- Interstudio: once-weekly meeting of all studio sections for an interactive lecture to solidify concepts and introduce new topics
- Student enrichment activities (SEAs): group homework assignments fostering creative integration and promoting transfer of chemical concepts
- Watershed project: design and implementation of a community or experiential learning project proposed by teams of students

The studios, SEAs, and watershed project were implemented in conventional laboratory space, while the interstudio was held in a typical classroom (with movable desks).[1]

The team selected and designed specific studio materials by the following method:

- Choosing a topic and establishing associated learning goals
- Researching the literature for alternative conceptions, teaching methods, activities, organizational strategies, and proven practices related to the topics and goals
- Brainstorming ideas and searching for relevant examples of the topic
- Meshing subtopics: (a) overlaying them on the learning cycle; (b) finding suitable proportions of time used for introduction, exploration, and discussion; and (c) filling in gaps
- Testing and reviewing usability and establishing specific evaluation criteria

The team held collective "research group" meetings to design and discuss individual tasks and then met as needed, in smaller groups. Studio course materials (see Supplementary Materials[W]) were prepared for delivery in HTML format via the Internet *(30, 31).* The HTML format was deliberately selected to allow students to access the same materials both in class (via laptops with wireless Ethernet connection) and outside of class and to utilize hyperlinks to explicitly relate concepts. The students used a standard general chemistry text for reference and practice problems.

Implementation

In this section, we provide brief snapshots of the four components of the course (also see Supplemental Materials[W]). A typical *studio session* (e.g., Periodic Table I) began with a mini-lecture on the origin of the atom to provide context for the four theories of matter and atoms (phlogiston, Dalton, plum pudding, and Bohr). Students were divided into groups to research and present a model of matter and atoms to the class. After the presentations on phlogiston and Dalton's atomic model, Dalton's work was further discussed to introduce the idea of systematically grouping the elements. Interactive demonstrations of the group I and II elements' reactivity with water were used to obtain student hypotheses on the grouping of elements in the modern periodic table. Mendeleev's 1871 periodic table was then used to introduce trends in the properties of elements as well as the concept of an undiscovered element. Students were then assigned an SEA where they were given a set of elements and elemental properties such as melting point, ionization energy, density, and oxide formed that they had to arrange into their own periodic table.

In a typical *interstudio session*, a homework problem that many students had trouble with was dissected. Two concept test questions followed. The students then worked in small groups with LEDs to explore real-world applications of periodic trends *(32, 33).* Finally, the watershed project was introduced to the class.

In a typical *SEA* (e.g., Equilibrium Representation) students were asked to create a presentation of a stable, dynamic equilibrium and a response of the system to a stress placed on it, using a medium of their choice. Their peers were responsible for discerning the source of the stress. This assignment has resulted in poems, songs, skits, and animations. The SEAs are a critical part of the course design because they provide an opportunity for the students to share their diverse talents, to effect peer-to-peer learning, and take initial steps towards ownership of the material.

In a experiential *watershed project*, groups of 3–4 students chose an area of water quality to investigate, proposed their method of investigation in a meeting with the instructor, submitted revised proposals, carried out their investigation, and reported their results in both written and oral form.

One group of students investigated the effect of different creek beds on the rate of phosphorus removal following a simulated spill. They collected samples of bed materials and created mock creeks with similar flow rates. After accounting for initial phosphorus content, they "spilled" some phosphates into their creeks and analyzed the phosphorus content over time using a colorimetric technique. The watershed project provides the key opportunity to practice the scientific method through student designed projects.

The first iteration of studio general chemistry *(34–36)* consisted of one 90-minute, multi-section interstudio (all 42 students) and two 2.5-hour studio sessions (up to 24 students per section) per week. The total time for the studio class (6.5 hours per week) did not exceed the class-time commitment of students taking both general chemistry lecture and laboratory concurrently (9 hours per week), but rather consolidated the contact time to better fit the anticipated needs of the new instructional design and included an increase in required workload outside of class meetings, that is, the SEA and watershed assignments. This course was an elective section of our traditional, one-semester general chemistry course and was offered for honors credit, although it was not a requirement for the students to be a part of the Honors College to participate. All of the students who chose to enroll were first-semester university students; 69% were students in the Honors College.

For the second implementation of the studio course in fall 2003, the studio sessions were extended from 2.5 hours to 3 hours to provide time to incorporate more SEAs and provide longer time for experimentation. This change increased the students' class time by an hour, but their total time in class (7.5 h) was still less than that of a student taking the traditional lecture and lab courses. In the second iteration, there were two sections (22 and 23) of first-semester students, all of whom were Honors College students.

The class was initially staffed by the design group: the postdoctoral fellow led the 90-minute interstudio and three graduate student instructors (GSIs) led the two studio meetings and assisted the class with the watershed project. Additionally, two fourth-year undergraduate instructors were employed as assistants for the course, one in each studio section. In the second implementation, we began to explicitly address the demands on and training of instructors who had not developed and written the course materials. One of the faculty members from the design group led the 90-minute interstudio and two first-year graduate students each led a set of 3-hour studio meetings. Another graduate student assisted the class with homework grading and the watershed project. By using electronic homework and relying on our experience to streamline projects, reduce grading demands, and improve GSI preparation, our goal is to staff a studio course with 1 GSI per 24-student section, which ultimately requires 2 studio GSIs for every 1.5 GSIs who would normally be assigned to our traditional lecture and laboratory classes.

Assessment of Student Learning

Summary of Evaluation Methods Used in Class

Since assessment drives student learning, assessment of the studio students needed to reinforce the course goals *(37)*. A noncompetitive atmosphere with an absolute grading scale is necessary, as students' fears of sliding down the "curve" may make them hesitant to assist their peers in a class with normalized grades *(30)*. Students arrive at college trained to take exams, and they will have to perform well on exams to succeed in their future courses. Yet, exclusive use of traditional problem-based exams for assessment would be counterproductive because they would not reflect the breadth of our goals *(38)*. Consequently, we retained exams, but made them focus on conceptual learning using open-response "explain questions" and asking students to solve problems based on data analysis. Exams accounted for 32% of a student's course grade.

Table 1. Scoring of Student Responses to Equilibrium Demonstration and Interview Questions

Questions	Phi Correlation	Significance
Effect of temperature on color?	–0.122	0.596
Rates of forward and reverse reaction	0.140	0.531
Dynamic nature	0.411	0.073
ΔH	0.378	0.131
Are all three vials in equilibrium?	–0.323	0.197
Addition of Cl^-	–0.218	0.329
Addition of $CoCl_4^{2-}$	–0.115	0.606

Six lab reports, which emphasized writing skills, data analysis, and understanding how the scientific community communicates results, accounted for 28% of a course grade. Lab reports and exams (60% of the final grade) were both individual efforts. Graded weekly homework consisted of a combination of instructor-written and assigned textbook problems. Homework was graded as incentive (13% of the final grade) for students to keep up with the course material, come prepared to class, and to address common misunderstandings of a topic. Students had the option of completing the homework individually or with others. The SEAs and watershed project were carried out in cooperative learning groups for 27% of a student's course grade. Assessment of the SEAs and watershed project was done using grading rubrics handed out to the students ahead of time; the same grade was assigned to all group members.

Course Goals: Integrated Understanding and Scientific Process

Through the SEAs and watershed projects, students have generated creative, scientific work attaining a value-added chemistry experience not found in a traditional course. Examples of these artifacts of learning are included in the Supplementary Material.[W] We submit the generation of the SEA and watershed artifacts as prima facie evidence for the goals of integrated understanding and scientific process. We do not at this time have data supporting the long-term impact of these activities on scientific learning and understanding.

Course Goals: Chemical Knowledge and Integrated Understanding

In the fall of 2002, 11 studio and 11 nonstudio students with statistically similar GPAs and chemistry and math placement scores participated in a post-course interview where they were asked questions concerning a demonstration of a chemical equilibrium (Table 1). The phi correlation was determined

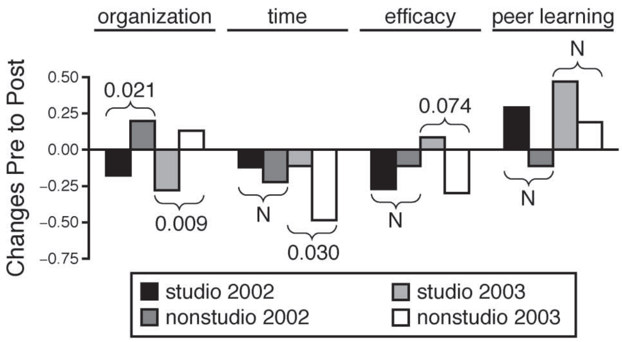

Figure 1. Significant changes in MSLQ scores holding for GPA, chemistry placement, and math placement. (If statistically significant, *p* values listed; if nonsignificant, then N.)

based on a 2 × 2 frequency response table of course versus correct or incorrect answer. Phi is a chi-squared test that takes into consideration small sample sizes. A positive correlation refers to a relationship between being in the studio course and answering the interview question correctly. A negative correlation refers to a relationship between being in the nonstudio course and answering the question correctly. The significance, or "*p* value", indicates the probability of rejecting the null hypothesis (that there is no relationship between the variables) when it is actually true. For example, a significance value of 0.1 means there is a 1 in 10 chance that we will incorrectly reject the null hypothesis. Although the two groups performed differently on different questions, a Mann–Whitney U or Wilcoxon W test indicated that the interview was equally challenging for both groups of students and that there was no overall difference in their understanding of equilibrium.

In the fall of 2003, five common multiple-choice questions on equilibrium and acid–base chemistry were incorporated on the final exam in both the studio and the regular general chemistry classes. Two of the questions were algorithmic and three were conceptual. Comparing the responses of the 45 studio students to a group of 347 nonstudio students, analysis by logistic regression model with GPA and chemistry and math placement scores as control variables, odds are even that a student from either group will answer two of the questions (one algorithmic and one conceptual) correctly. Of the three remaining questions studio students were more likely to answer two of them correctly (slightly higher odds and 3:1 odds) and nonstudio students were more likely to answer the third correctly (3.4:1 odds). (See the Supplemental Materials[W] for questions.)

Both of these quantitative measures of chemical understanding lead us to conclude that overall chemical knowledge attained by studio and nonstudio students on the topic of equilibrium and the students' integrated understanding assessed from interview responses is comparable.

Course Goal: Learning Community

The Motivated Strategies for Learning Questionnaire (MSLQ) *(39)*, a validated instrument containing Likert-scale questions on 12 topics, was used to collect information on both studio and a random set of nonstudio students' learning strategies in their respective courses *(40)*. The MSLQ was administered both at mid-semester and at the end of the semester.[2] Results were analyzed using a repeated measures ANOVA controlling for differences in students' GPA, chemistry placement scores, and math placements scores. In 2002, studio students exhibited a statistically significant difference from nonstudio students ($p = 0.021$) in use of organizational techniques such as outlining and use of charts, diagrams, and tables (Figure 1) *(36, 41, 42)*. We attribute the decrease reported by studio students to the chaos associated with the first implementation of a new course; exposure to a large variety of teaching techniques; and the expectation that students individually develop (rather than being supplied with) their learning aids. Peer learning (studying with classmates and planned explanation of material to peers) was not reported significantly differently by studio versus nonstudio students. However, the self-reported increase in peer learning by studio students supports achievement of our fourth goal of building a learning community. Finally, we were assured that our student populations were inherently similar by the lack of significant differences between the two groups in the areas of extrinsic motivation, rehearsal, elaboration, and study environment.

The MSLQ survey and analysis was repeated in 2003. As was observed in 2002, studio students showed a decrease in reported use of organizational techniques over the course of the semester while nonstudio students reported an increase ($p = 0.009$, Figure 1). Other significant changes between the studio and nonstudio classes in 2003 were efficacy ($p = 0.07$) (students rating themselves high in efficacy are confident that they possess the skills to be able to accomplish a task) and time management ($p = 0.03$). Although the difference in efficacy is not highly significant, it is reassuring to see a positive change in the confidence of the studio students, especially compared to the decrease observed in 2002, and particularly because self-efficacy typically diminishes owing to the optimistic overestimation of success that students have at the beginning of introductory college courses *(37)*. The significant difference in time management (setting aside time to study, attending class, and keeping up with assignments) between studio and nonstudio is attributed to the smaller studio class where students rely on their peers for success in completing many activities, resulting in higher class attendance. In 2003, studio peer learning increased even more than in 2002, again supporting our fourth goal of effective building of a scientific learning community.

Student Challenges

In implementing the studio course, we received comments from students similar to those reported by those who implemented the ChemConnections Modules *(5)*. Some students felt like "guinea pigs", taking part in some unpleasant experiment where they had to work much harder than other students in the "easier" lecture sections of the course. The resistance to a change in instructional style originated in student expectations and experiences of being told what they needed to know and then feeling cheated for having to work for it *(30)*. This clash of expectations with studio is a particularly acute problem for first-semester Honors students, who have cruised through high school chemistry courses. We also encountered the typical struggles in implementing collaborative learning with groups of students who thought that helping others was a waste of time or who were convinced that group members did not carry their weight *(30).* Finally, students had a hard time finding the connections between the class components and assessment tools (studios, SEAs, interstudio, homework, and exams.)

Each implementation produced two sections that, while mostly independent of one another, were yet their own close-knit community, atypical for most large-university, introductory-level courses and proven to increase student retention in college *(43).* The students made many comments regarding this sense of community as being one of the most rewarding aspects of this course, "Group work is a lot of work, but a benefit. It helps you get motivated." Others recognized some of the various benefits of group work, "Working in groups helped to develop our communication skills," and "I don't like working in groups…I am a self-learner although explaining things to others helped to solidify things."

Staffing Studio Chemistry

A lingering concern about further implementations of the studio course was using first-year graduate students who have never been exposed to studio teaching and learning. In general, the question of who implements reforms is considered separately, if at all, by those who develop them. There is precedent for a negative impact on the students whose courses were taught using modules and where the GSIs resisted or felt negatively about using the nontraditional teaching method *(5).* Other evidence suggests that most GSIs will default to teach in the manner that they learned and were taught *(44, 45).* It has also been shown that GSIs who have had a negative experience with inquiry-based teaching methods while they were students will also work to "save" or rescue their students from the frustrations that they experienced by giving their students too many guidelines *(44).* One of the GSIs teaching the studio course reported that one of the greatest challenges was "making sure that I didn't divert to what I was used to, the 'traditional' lecture format."

The graduate students selected to teach the studio course were chosen based on their personal interest in learning or experiencing this teaching format. In order to assist the GSIs in preparing for their studio teaching experience, we had them spend 2–3 days prior to the start of the semester working with the course instructor learning and practicing the "why's" and "how's" of teaching in a student-centered environment. Throughout the semester, GSIs were required to read two short articles on misconceptions, active-learning techniques, and so forth, each week and to attend a weekly staff professional development meeting where these articles and any personal classroom issues were addressed.

Conclusions

A new value-added general chemistry course, using the studio instructional method to incorporate current educational research was designed and implemented at this university. Many literature-based activities designed to effectively teach chemistry concepts and confront misconceptions were adapted. These teaching methods and activities were woven into the course to provide the students with ways of learning chemical concepts and practicing scientific discovery, creativity, and community.

Studio general chemistry successfully provides significant "value added" while maintaining the key content mastery needed to continue in science or engineering classes. The studio course achieves our first assessment goal through highly creative content generated by students demonstrating integration of their scientific thought process into other aspects of their lives and their intellectual activity during the course. We hope this bodes well for a continued integration of the scientific thought process into students' intellectual problem solving. Our second goal of making sure that the studio course is at least equivalent to our traditional general chemistry course in student exam scores was met as shown by interview-based assessment and common final exam questions measuring student understanding of chemical equilibrium. Our long-term goals of developing scientific-reasoning skills for later careers, equipping students to make informed decisions, and improving the attraction of inquisitive and bright young people to the sciences are difficult or impossible to assess over a short time period and cannot yet be answered. The studio course addresses the ever-growing age, social, and ethnic diversity of our student population.

The studio course is in its fourth implementation, being offered to non-Honors students using the fourth generation of course materials. The goal of the studio project is expansion to a larger number of students by gradually adding sections that will make the course available to a more diverse group of students. This goal makes the success of the project important and attractive not just to this university, but also to institutions looking to adopt chemistry learning environments that address the needs of growing and diverse student populations. Further evaluation of methods and materials will be carried out with results and course materials communicated to the chemical education community.

Notes

1. In 2002, a set of 24 laptops with wireless Ethernet connection, a projector, and a projection screen for the instructor's computer were added to the laboratory. In 2003, an interactive whiteboard was used in both the studio laboratory and the interstudio classroom.

2. The MSLQ was administered in collaboration with Wilbert J. McKeachie and his undergraduate research student, Jessa Stewart, both from the University of Michigan's department of psychology.

[W]Supplemental Material

Examples of a studio, a SEA, and a watershed project; a course syllabus; equilibrium interview scoring; common exam questions; and the instructor's impressions are available in this issue of *JCE Online*.

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